On the Feasibility of UMTS-based Traffic Information Systems

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Abstract

Intelligent Transportation Systems (ITS) are a hot topic in the communications society. Currently, research is primarily focusing on setting up Vehicular Ad Hoc Networks (VANETs) based on WLAN technology. However, VANETs are heavily dependent on high market penetration or infrastructure support. Third-generation (3G) networks might complement these efforts. They are already widely deployed and can serve as the basis for Car-to-Infrastructure (C2I) applications. We developed a simulation framework for holistic analysis of complex UMTS-based ITS. This framework couples simulation models with corresponding protocols of the UMTS link level, of higher network layers, and of road traffic. Based on our simulation framework and real-world 3G network coverage data, we evaluated a UMTS-based Traffic Information System (TIS) in a typical highway scenario in which information about traffic jams needed to be communicated to other cars for optimized route planning. The evaluation clearly outlines the capabilities of the simulation framework and evaluation results are consistent with all expectations. For example, we show that the availability of UMTS multicast distribution services are demanded for an efficient operation of the TIS application.

Key words: Intelligent Transportation Systems, Car-to-Infrastructure, UMTS, Performance Modeling

1. Introduction

Recently, the communications society intensified its focus on vehicular communication architectures and protocols. This includes scenarios such as safety applications, but at the same time, these mechanisms are also intended for use in general purpose Traffic Information Systems (TISs), e.g. for optimized route planning. Basically, two approaches are competing in this field: Car-to-Car (C2C) and Car-to-Infrastructure (C2I) communication architectures. Presently, mainly WLAN according to the IEEE 802.11p standard [1] is used in this domain. However, for general purpose TISs these C2I applications require massive investments into a new infrastructure, e.g. along highways. C2C communication solutions address this problem by using the moving vehicles as a dynamic infrastructure established by Vehicular Ad Hoc Networks (VANETs) [2, 3]. An example is the approach taken by the Self-Organizing Traffic Information System (SOTIS) [4]. Whereas it has been shown that this system works well even with a low penetration of SOTIS installations, new problem domains are opened, e.g. the increased end-to-end delay and the reduced quality or granularity of the available information. Furthermore, security is an aspect in terms of drivers' privacy and information security for closed user groups.

3G telecommunication networks, specifically UMTS, are a relatively new player in this field [5, 6] and offer a couple of benefits for TIS applications. Owing to their system design, in conjunction with much larger data rates compared to 2G networks, TIS operation based on 3G networks becomes economically feasible. In addition, unlike C2I solutions using WLAN or WiMAX, UMTS-based solutions can rely on readily-available infrastructure.

Compared to WLAN-based TIS solutions, however, the perceived strengths and weaknesses of UMTS networks are quite different. While, for example, the security of C2C networks cannot easily be guaranteed [7], there already are strong security measures in place to guarantee 3G networks' integrity, which can be re-used for C2I communication. As a second example, the distance between a message's sender and its intended receivers is almost a non-issue in 3G networks: its impact on the end-to-end delay is negligible. On the other hand, even for short-distance messages the end-to-end delay is already quite high compared to that of direct radio links.

A key question to be asked about an infrastructure-based C2I communication system is therefore whether end-to-end delays will still be acceptable not only for common TIS applications, but also for the transmission of hazard

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warnings. Another important question is whether such a system will scale better [8] than more traditional WLAN-based C2C solutions to accommodate high penetration rates, given that in this C2I solution all network traffic has to be routed through the available infrastructure. Together with obvious business reasons, both questions are at the core of the problems which hindered adoption of some of the early 2G-based approaches [9] to C2C and C2I communications via a cellular network proposed in the 1990s. Development of C2I solutions is now picking up again, with new approaches based on 3G networks.

The state of art in cellular communication already allows for interesting and proven applications in the domain of Intelligent Transportation Systems (ITS), one such application being the derivation of estimations on traffic density from passively acquired cellular network data and its distribution to end users within minutes, marketed as e.g. the *TomTom HD Traffic* service. New technologies in UMTS networks, however, promise delays of less than one second while at the same time reducing network load.

Recent work in this field has mainly dealt with analytical evaluations of only some of such a communication system's aspects [6]. By means of an analytical model, the authors quantified the achievable performance in some realistic scenarios. In particular, the advantages of the Multimedia Broadcast Multicast Service (MBMS) were studied, which is needed to support efficient C2I services on top of the UMTS network if the number of users is high [10]. Although MBMS is still lacking widespread commercial adoption, interoperability tests and several trials in operators' networks have already proven the standard ready for adoption.

Experimental approaches have accomplished post-hoc analysis of implemented testbeds using state of the art technology. In these setups, either detailed studies have been conducted [5] or complex extensible testbed architectures have been developed [11]. However, only the currently deployed UMTS versions could be tested and the size of the experiments was limited. Moreover, an evaluation of the environmental impact of TISs based on real-world experiments is infeasible, and even simulative studies on this topic are rare [12].

Simulation experiments of UMTS networks are usually performed using proprietary models without focus on application in vehicular environments, e.g. in [13], and without incorporating realistic mobility models. Furthermore, such simulations are not using a holistic approach, i.e. they are not including all system aspects from the wireless links to the core 3G network as well as influence of the road traffic. Even for WLAN-based C2C approaches, it has been shown that coupled simulation of network communication and road traffic is necessary [14, 15].

Comprehensive evaluations of such vehicular communication systems, using features which are still in the early planning stages, can, however, be performed if all components of such a system are modeled in sufficient detail and assembled into a simulative testbed. Therefore, we developed a new simulation framework that allows such a *holistic analysis* of complex 3G-based TISs. Our simulation framework, *Veins* (Vehicles in Network Simulation), is based on a bidirectionally coupled environment for network simulation and road traffic microsimulation.[1] *Veins* has also been used for recent studies of VANET protocols [16].

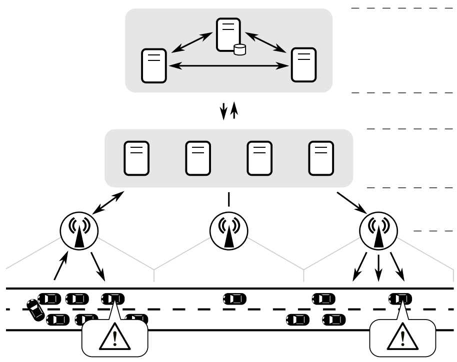


Figure 1: Component model of the simulated UMTS-based C2I communication system

Our simulation framework *Veins* is being used for the simulative evaluation of a planned real-world communication system, which is currently being designed in the Cooperative Cars (CoCar) project [17]. Aside from examining the technological feasibility of such a system, CoCar also addresses establishing a solid business case [18]. The project is part of the German government funded research initiative Aktiv[2], which encompasses research in the fields of traffic management, active vehicle safety, and cooperative systems.

The simulation framework also includes a set of CoCar application layer protocols, to be used in both the up- and downlink direction. These protocols benefit from new features of cellular communication systems, e.g. the current High Speed Packet Access (HSPA) system which improves up- and downlink data rates and transmission latencies. For easy integration into existing, standardized communication systems, these protocols are implemented above the cellular communication protocol stacks.

In this paper, we show first simulation results for a typical highway scenario, based on real-world 3G network coverage data. The results clearly outline the capabilities of the simulation framework and evaluation results are consistent with all expectations. Figure 1 depicts an overview of the CoCar communication system, along with the various models that have been integrated to form the testbed we will use for evaluations. Based on the example of the CoCar system, we describe in this paper each of the models the framework is composed of and detail how the models interact with each other.

[1] http://www7.informatik.uni-erlangen.de/veins/
[2] http://www.aktiv-online.org/

The paper is structured as follows. First, Section 2 introduces the application models. Section 3 gives an overview on the Internet, Core Network, and radio access network models used. Section 4 details the UMTS channel model that was integrated with the simulator and Section 5 introduces the road traffic model. Finally, first results that we obtained in a proof-of-concept study are outlined in Section 6, focusing on the single use case of traffic jam warning exchange. This also includes a discussion of the impact they will have on a real-world implementation. Section 7 concludes the paper.

2. Application Models

In the simulative testbed, components at the network edge are represented using detailed application-layer models of the respective services. These components are the Traffic Information Center (TIC) and the CoCar-enabled vehicles. Both send and act upon bit-precise representations of CoCar messages.

Three application-layer protocols have been specified in order to handle communication among vehicles in the CoCar system. One protocol, called Traffic Probe Data Protocol (TPDP), is a lightweight binary protocol that serves to provide regular traffic condition updates to the server. As stated, we are focusing on the use case of warning message exchange, so in the simulation model only the two other protocols were deployed.

As illustrated in Figure 2, in the uplink, vehicles use the Fast Traffic Alert Protocol (FTAP) to send messages to the CoCar TIC. FTAP messages are sent in a very compact, binary representation. In the downlink, these messages are quickly broadcast to all vehicles in the same cell, again using the FTAP protocol.

In a second step, the TIC aggregates all received messages' contents to maintain a higher-level view on traffic conditions, potentially integrating information from external sources. From this high-level view, a pool of CoCar messages is then derived.

These messages are using a message format based on that of the Transport Protocol Expert Group (TPEG) protocol suite, which defines a standardized means of traffic data exchange between cooperating parties and with end users. CoCar messages were integrated with this suite, specifying missing CoCar information elements to form a TPEG-conformant message type [19], called an *application* in TPEG terminology. This CoCar Application builds upon, but is independent from other standardized TPEG applications. CoCar application messages are formatted using XML and are conformant to the TPEG XML protocol standard series [20]. By this means, CoCar messages can be very flexibly handled: On the one hand, they can be used alone, without any other TPEG application; on the other hand, they can be easily integrated into a TPEG message stream and transferred to the clients using other applications. Traffic messages in the pool are then periodically geocast in the form of a TPEG carousel.

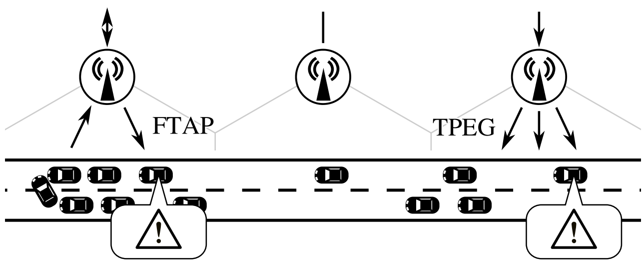


Figure 2: Protocols used in the CoCar communication system

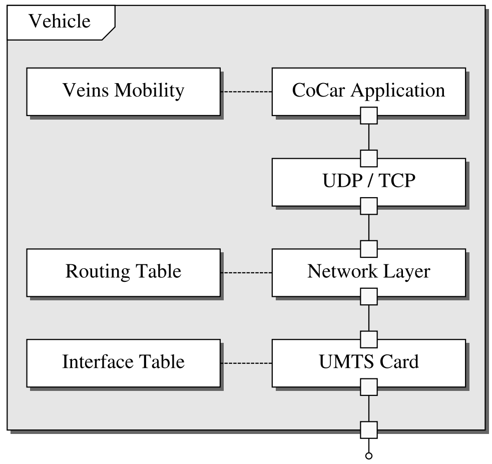


Figure 3: OMNeT++ representation of a CoCar-enabled vehicle in UML notation

The CoCar specific protocol is built upon the IP and UMTS protocol stacks. The selection of transport layer protocols, such as UDP or TCP, depends on the functional requirements as well as on performance requirements of the applications, like the message transmission delay.

For the simulation of message transmissions, we used the OMNeT++ simulation framework [21]. OMNeT++ runs discrete, event-based simulations of communicating nodes on a wide variety of platforms and is free for academic use. It is getting increasingly popular in the field of network simulation. Scenarios in OMNeT++ are represented by a hierarchy of reusable modules written in C++. Modules' relationships and their communication links are stored as *Network Description* (NED) files and can be modeled graphically. Simulations are either run interactively, in a graphical environment, or are executed as command-line applications.

Figure 3 shows the OMNeT++ representation of a CoCar-enabled vehicle and illustrates its modular buildup from logical components, which realize the functionality described in the following.

Vehicles in the simulation model receive traffic information messages via modules representing a UMTS card and keep a record of traffic conditions. They are also configured to continuously monitor the state of their containing node's mobility module. When the node is detected to have inexplicably stopped for an extended period of time it assumes that a traffic jam has occurred. In the application-layer model, a vehicle then generates a traffic message and sends it via its UMTS card to the TIC under two conditions: The vehicle did not yet receive a similar incident warning and enough time has passed since the incident was detected to compensate for the round trip time of traffic messages that might be underway.

The TIC of the simulation model serves as the CoCar system's core component which can collect and process CoCar specific application messages from authorized cars and from auxiliary traffic and travel information service providers. The TIC is located outside the UMTS core network, connected via the Internet. It thus communicates with the wireless network via the UMTS core network components and provides interfaces to other service providers.

In order to obtain realistic results, application layer models employed useful techniques to avoid unnecessary message transmissions, such as micro-aggregation of FTAP messages at the server side prior to them being re-broadcast to the same cell and client-side duplicate avoidance by keeping track of what was already reported to the TIC. Several parameters were introduced that allowed a fine-tuning of the application layer models' behavior to guarantee optimum performance. Among these configurable aspects are:

- Variable FTAP and TPEG message configurations to examine trade-offs between system performance and different message and header lengths, e.g. to provide support for security elements.
- Bandwidth limits to be observed by the TIC to examine the impact of CoCar transmissions on the core network vs. reduced delays.
- Freely-configurable message repeat intervals and validity timeouts to examine how best to balance network load and dissemination speeds.
- Architectural variants of the communication infrastructure, to help judge in what direction core network components of the UMTS should evolve.

3. Network Models

The number of parallel unicast connections in UMTS is limited by the cell size: The distance between a mobile terminal and its associated NodeB determines the path loss for the radio connections. A vehicle that is far from the cell's center will require a higher transmit power to communicate with the NodeB. This, in turn, increases the overall interference level of the cell. Since UMTS is an interference limited system, this reduces the number of possible simultaneous connections in the cell, eventually leading to new connection-requests being blocked.

In order to avoid unrealistic simulation setups, nodes representing UMTS base stations were therefore set up in the simulated area according to real-world 3G network coverage data provided by Vodafone Group R&D Germany, with typical cell sizes ranging from 500 m in populated areas to approx. 4500 m in the countryside.

Three network elements are used to transmit messages received at the UMTS base stations, i.e. the NodeBs, to the communication system's TIC. All NodeBs are connected via the radio access network to the UMTS provider's core network components. These components relay messages via the core network to a GGSN, where they are commonly re-framed for transmission over a public network and to their destination, the TIC.

Real-world algorithms for packet scheduling and optimization are intellectual property of network operators and the actual network design varies widely between different implementations. In the simulative testbed, both the radio access network and the core network components are therefore simulated at an abstract level: All base stations were transparently connected to a node representing the GGSN and the processes of message scheduling and transmission were reproduced using statistical models of the radio access network and core network.

However, all protocol adaption and re-framing at this gateway node was performed using the well-tested models of the OMNeT++ *INET Framework* extension for Internet models. The *INET Framework* provides a set of OMNeT++ modules that represent various layers of the Internet protocol suite, e.g. the TCP, UDP, IPv4, and ARP protocols. This made it possible to simulate the link between gateway and TIC using detailed models of an Ethernet link, as well as the network cards and all protocol layers up to the transport layer.

4. Channel Model

Actually performing all signal processing tasks that take place on the UMTS physical layer for every single network connection is infeasible in terms of computational effort and memory consumption. Instead, performance measures should ideally be modeled on a higher level.

Therefore, realistic simulation of UMTS channels was accomplished by creating a dedicated link level simulator and performing extensive simulations of packet transmissions. In the following, we detail how a set of statistical models was derived from the results of these simulations to serve as the basis for a simulation module modeling bit errors and delays encountered during UMTS packet transmissions.

Channel quality in the UMTS system has a dependency on vehicle speed, which is a continuous figure. Thus, for the simulations, a range of discrete vehicle speeds was picked and for each, as well as for all combinations of remaining input parameters, a separate set of simulation results was obtained. Subsequently, the results of these

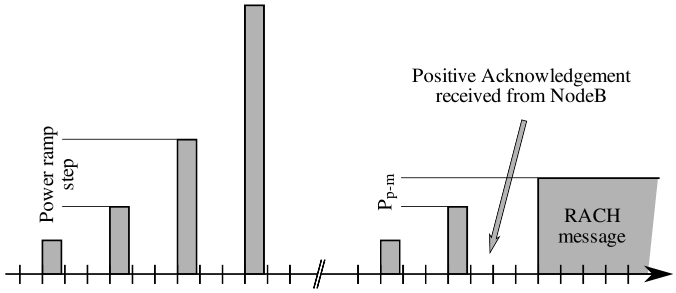


Figure 4: Access procedure on RACH: One failed, one successful attempt

simulation experiments were used to derive distribution functions for all involved statistic variables.

For each radio transmission to be evaluated in the target simulation framework, the simulation module then interpolates between the two most closely matching distribution functions for a vehicle's speed and for the current communication parameters to arrive at a bit error rate and the transmission's delay and duration.

4.1. Random Access Channel (RACH)

Data in a UMTS system will typically be transported via a Dedicated Channel (DCH), which needs to be established for each communicating mobile device and which requires considerable network resources to be maintained. For traffic warning messages in the CoCar system, the use of DCHs is envisioned to be too costly time-wise and resource-wise, so the small messages sent by entities of the CoCar system to the TIC are transported over the RACH.

The RACH is a common uplink transport channel that can be used by mobile terminals to request the establishment of a dedicated channel. It can, however, also be used to transmit small amounts of user data. Figure 4 illustrates the RACH access procedure. RACH preambles, consisting of 16 repetitions of a spreading sequence of length 256 chips, are sent with increasing transmit power as long as no positive acknowledgment is received from the NodeB or until the predefined maximum number of preambles is reached. In the latter case, the physical layer access procedure terminates unsuccessfully but another set of preambles can be sent when signaled from the MAC layer.

The slotted aloha scheme is used to access the air interface, which means preambles can only be transmitted at fixed points in time, called access slots in UMTS. Two radio frames (20 ms) consist of 15 access slots, which amounts to $^4/_3$ ms per access slot. The access service class for a given service, in our case CoCar FTAP, defines the set of subchannels that is assigned to it. The sub-channel defines the concrete locations of the access slots that a service is allowed to transmit in. Note that one access service class can contain more than one sub-channel, thus reducing the time between two consecutive access attempts [22].

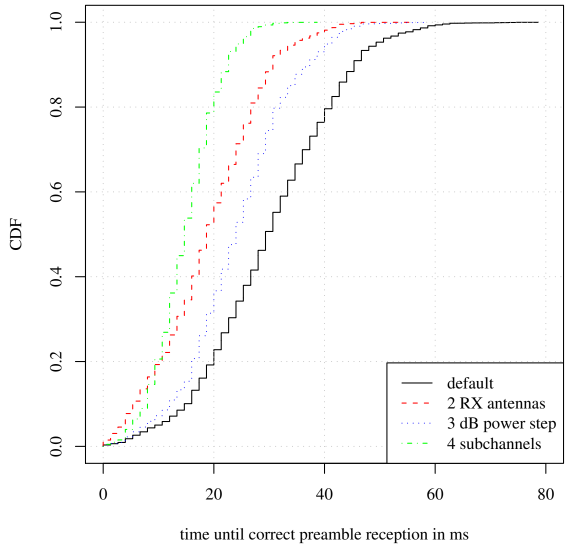


Figure 5: CDF of the random access procedure duration for the default set of parameters (c_0=−6 dB, 2 dB power step, 1 RX antenna, 2 RACH subchannels), compared to alternative parameterizations

4.1.1. Simulations

The simulation results (Figure 5) depict the distributions of the delay times that can be expected for various RACH parameter settings. Specifically, the delays consist of the time that passes between message generation in the mobile terminal, the subsequent power ramping phase, and the correct detection of the access preamble by the NodeB.

Table 1 shows the parameters that were used in the overall performance evaluation. The solid black line of Figure 5 represents those default parameters, whereas the other curves were generated by varying a single parameter each. All simulations use the ITU Vehicular B power delay profile for modeling multipath fading. Transmission times for data are not included in the figures. Since these are deterministic values, they can be added as a constant factor as needed.

4.1.2. Conclusions

The simulation studies show that the access times for the RACH can be influenced by a number of operator-chosen parameters.

The *number of sub-channels* that is available for a particular service determines the frequency of the allowed ac-

Table 1: Default set of parameters for RACH

Spreading Factor	32
No. of receive antennas	1
Vehicle speed	0...130 km/h
Power step	2 dB
No. of sub-channels	2
Size of message	70 byte

cess attempts and, therefore, the capacity of the RACH. Increasing the number of RACH sub-channels has shown to yield a linear gain in latency, at no additional cost. However, note that there is only a total of 12 sub-channels available for all services and a minimum of 3 access slots, which equates to 4 ms, must remain unused between two consecutive access attempts [23].

The *power step size* must be chosen rather carefully. For a single user, a larger step size will increase the probability of each preamble to be successfully detected by the NodeB. However, in a typical multi-user scenario, the interference caused by each access attempt's final preamble will negatively affect the transmission of all other users, thus increasing delay times. The power step size can be chosen from the range 1 dB to 8 dB, with 1 dB steps [24]. As a trade-off, a power step size of 2 dB is recommended here.

Finally, the number of receive antennas of the NodeB is taken into account. As can be seen from Figure 5, NodeBs equipped with antenna arrays will be able to achieve a considerable gain in detection performance, which can greatly reduce delay times on the air interface.

Although the choice of parameters is rather conservative, our system is able to maintain sufficient QoS to support even time-critical applications. As can be seen in Figure 5, performance can be still be increased if necessary.

4.1.3. Example

Consider the parameters shown in Table 1 for the realization of a RACH. The solid black curve (labeled *default*) in Figure 5 depicts the delay distribution for this specific set of parameters. Obviously, 90 % of all access procedures take about 55 ms or less to complete. Using a spreading factor of 32 results in a data rate of 120 kbit/s on the physical layer, or 150 byte/frame. The duration of a frame is 10 ms.

Taking into account the channel coding and overhead from the higher protocol layers, we find that the 70 byte message cannot be transmitted during one frame but must be split into two. Subsequently the total delay for 90 % of all access procedures amounts to:

$$45\,\text{ms} + 2 \times 10\,\text{ms} = 65\,\text{ms}. \tag{1}$$

Messages that do not fit into two radio frames would have to be split further and a new access procedure is required after each two consecutive frames, which will again increase the time to complete the data transmission, so in the CoCar system only FTAP messages, which will fit into at most two RACH frames, are transmitted via the RACH.

4.2. Forward Access Channel (FACH)

The UMTS Forward Access Channel (FACH) is a UMTS common downlink transport channel. Messages that are sent by the NodeB using the FACH can be received by all mobile stations in a cell. It can thus be used for multicast transmission of messages via the UMTS Multimedia Broadcast Multicast Service (MBMS).

In the Forward Access Channel (FACH) simulation model we used, transmission of a message of size n on this channel takes:

$$t = \left\lceil \frac{n}{40\,\text{byte}} \right\rceil \times 10\,\text{ms} \tag{2}$$

This is because messages are transmitted on the FACH in discrete slots of 10 ms each. Implementers of the FACH can choose between a number of different slot formats, detailed in [22]. This results in different spreading factors being used and different channel bit rates being available for transmissions. In our evaluations, we assumed a FACH parameterization that allowed 40 byte of data to be sent in one frame.

Therefore, multicast downlink messages in the CoCar system are ideally transmitted over the UMTS FACH. If no multicast capability is present in the communication system, UMTS DCHs are used.

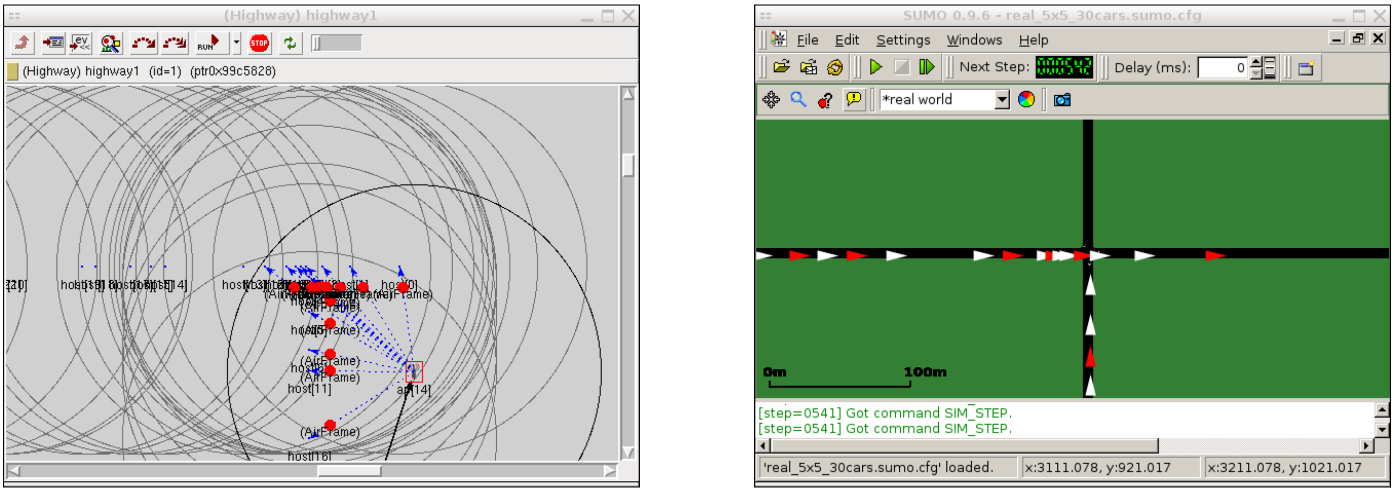
5. Road Traffic Model

One of the goals of the simulator was measuring the impact of the CoCar communication system on the road traffic, in terms of metrics such as users' travel times, smoothness of traffic flow, and the associated environmental impact of the TIS. The choice of the mobility model has been shown to influence the outcome of simulations to a large degree [15, 25]. Simulations were hence based on the *Veins* framework, which allows a realistic node mobility model to be employed [14].

Traffic simulation in the high level simulator is performed by coupling with the running simulation a dedicated traffic simulator, SUMO [26], which uses the microscopic traffic model of Stefan Krauss [27] and is developed by German research organizations DLR and ZAIK. Both simulators exchange state information at run time, allowing not only vehicle movement to influence the network layout, but also network events to e.g. change routing decisions of drivers and, hence, influence vehicle movement. Figure 6 shows screenshots of both simulators running such a bi-directionally coupled simulation of traffic streams merging at an intersection.

Serving as communication scenario of the proof-of-concept evaluation was traffic in the area of a large motorway interchange next to Frankfurt Airport. This region, where two major German motorways (A3 and A5) and one large trunk road (B43) connect, was chosen because of its overlap with the testbed of the German research initiative *SIM-TD* and because of the challenges it poses to routing and traffic optimization.

Figure 7 gives an overview of this region, which spans approximately 10 km × 10 km. In this area, all traffic on roads classified as "Autobahn", "Schnellstraße", and



(a) Event-based network simulation

(b) Road traffic microsimulation

Figure 6: Screenshots of simulators' GUI versions running network and road traffic simulations in parallel

"Bundesstraße" (motorway, trunk road, and primary road) was simulated.

The mobility models of simulated vehicles were configured to model two distinct vehicle classes, loosely representing cars and trucks, their parameters set to the values given in Table 2. This parameter set lead to a diverse mix of vehicles participating in the scenario, which in turn lead to very dynamic traffic patterns emerging during simulations. A lane-precise road network model was employed, based on data available via the OpenStreetMap[3] project.

Traffic flows of 2000 vehicles were set up in the east-west and west-east directions of motorway A3, keeping the number of simulated cars at a manageable level, but at the same time allowing for a multitude of alternative routes, e.g. along trunk road B43.

Realistic movement of cars was achieved by first iteratively pre-computing routes for all vehicles until a steady state regarding route selection was achieved. The mobility scenario was then modified by adding an artificial traffic obstruction, namely the closing of two out of three lanes at the motorway interchange, preceded by a short section of motorway that imposed a 60 km/h speed limit on all vehicles. No adjustment of pre-computed routes was performed for this modified scenario, so all vehicles started out unaware of the presence of the obstruction. This way, the traffic pattern in the vicinity of the obstruction quickly reached congested conditions with densities peaking at 365 vehicles within the service area of one UMTS cell.

In order to compare mobility scenarios in terms of smoothness of traffic and the associated environmental impact, we integrated the EMIT model [28] of vehicle emissions with our mobility model. We already used this model to evaluate VANET-based TIS solutions and were able to show the large impact that re-routing of cars had on network metrics [29, 16]. This model calculates emissions depending on vehicle speed and acceleration, taking into account its individual characteristics such as total mass, engine, and installed catalytic converter. EMIT authors calibrated the model for a wide range of different emission metrics, of which we picked tailpipe CO_2 emissions in g/s. Compared to real-world measurements, they claim an error in CO_2 emission calculations of approx. 2.2 %, assuming the catalytic converter has reached operating temperature.

Table 2: Road traffic microsimulation parameters and their values

Parameter	Car	Truck
Fraction of vehicles	80 %	20 %
Mobility model	Krauss	Krauss
Maximum speed	35. . . 70 m/s	22. . . 28 m/s
Maximum acceleration	2.60 m/s^2	1.30 m/s^2
Desired deceleration	4.5 m/s^2	4.0 m/s^2
Assumed length	5 m	15 m
Driver imperfection σ	0.5	0.75

At the end user side, the road traffic model is combined with application models in order to generate a realistic data traffic load for the whole CoCar system. Vehicles could then use the CoCar communication system to exchange information about perceived traffic jams, causing all receivers of such a warning to adjust their routes to avoid affected roads.

6. Performance Evaluation

The first and foremost benefit of any TIS is, of course, the increase in overall road safety which it can effect not only by assisting users, e.g. with route planning, but also by providing early and accurate jam and hazard warn-

[3] http://www.openstreetmap.org/

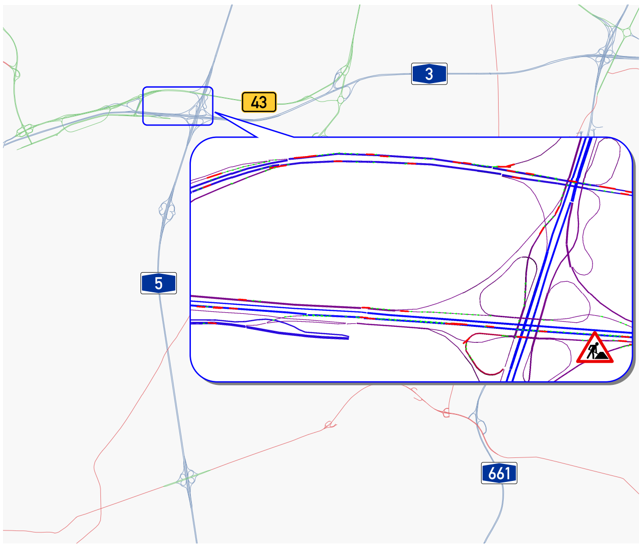


Figure 7: Road map of the 10 km × 10 km simulation scenario and GUI screenshot of the traffic simulator, showing a section of the motorway interchange during the simulation

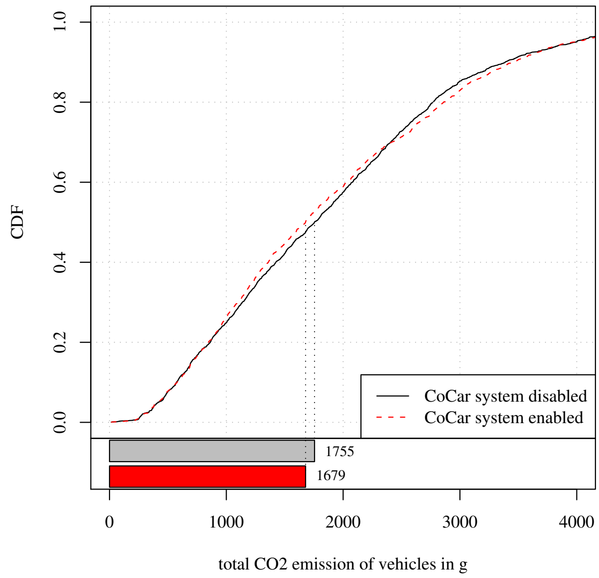


Figure 8: Impact of the CoCar communication system on road traffic: Quantiles of vehicles' CO_2 emissions.

ings. Secondly, TISs can facilitate dynamic re-distribution of traffic, decrease local traffic densities and thus lead to smoother traffic. However, operational parameters of a 3G-based TIS (in particular when optimizing for timeliness of messages) have to be balanced with the load it will exhibit on the network infrastructure, which is shared with other applications.

Based on the introduced simulation framework, in this section we outline selected results from these three problem domains, obtained in a proof-of-concept study modeling the interworking scenarios of communications and road traffic. In particular, we provide answers to the following questions:

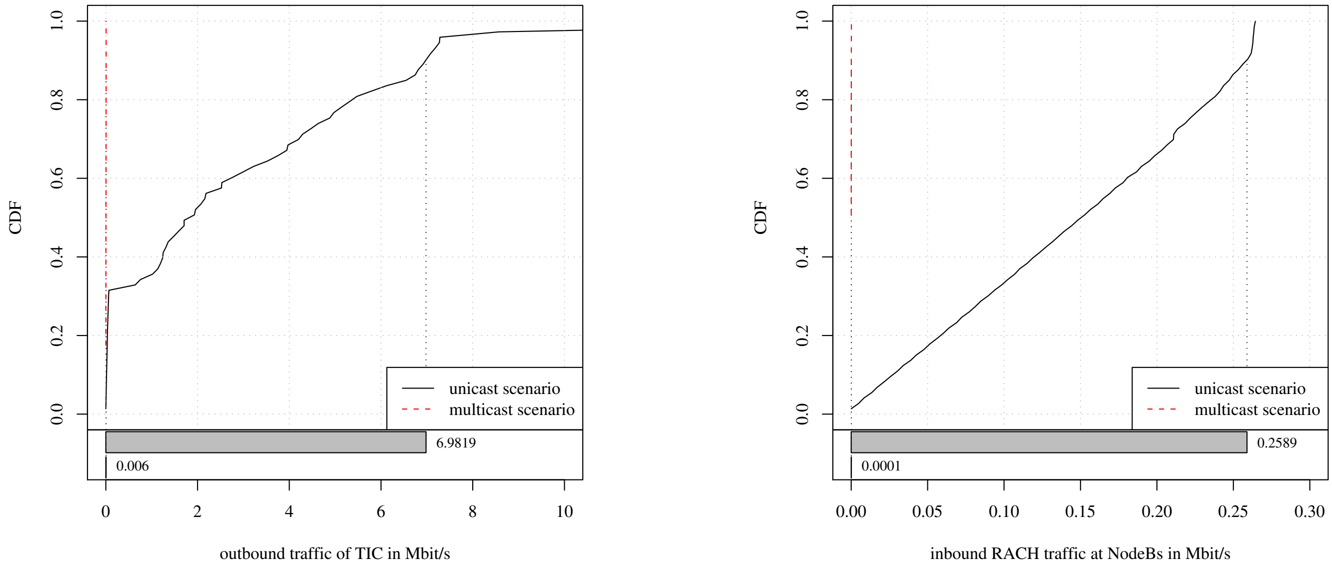
- Will the system strike a balance between smoothing traffic and at the same time not send vehicles on unnecessarily long detours? As the quality of this balance is directly reflected in overall traffic emissions, we first examine the impact system operation has on CO_2 emissions.
- How much strain will different system configurations put on the network infrastructure? What is the network load on the air interface, the core network and on the servers?
- How timely will vehicles learn about a new event, either in the immediate vicinity or at an arbitrary location? What end-to-end delay can be expected for messages received via FTAP or via TPEG?

Multiple simulation runs were carried out and the results evaluated using R [30]. They are shown in the form of empirical Cumulative Distribution Functions (CDFs), plotting for a range of values the probabilities of a measure yielding at most a specific one. Hence, the median of a measure will be associated with a CDF value of 0.5, or e.g. the first quartile with a value of 0.25.

In addition, in order to evaluate the designed application layer protocols we also studied the application processing performance in the CoCar TIC. Although it is well known that XML is a simple, flexible, platform-independent language for representing structural information exchanged across application components, compared to binary means of data representation the processing of XML messages is highly inefficient. Especially in the TIC, the essential component for processing collected information from the CoCar end users and other service providers – how to access, modify and vary information elements efficiently – is a key issue when a large number of vehicles are communicating via the CoCar system.

6.1. Impact on Road Traffic

Figure 8 shows the results of the first evaluation, examining the impact of the CoCar communication system on the environment. It plots the CDF of all vehicles' total amount of CO_2 emitted during their travel from start to destination, independent of the length of their route. As can be seen, activating the CoCar communication system in simulations did not lead to an increase in participants' CO_2 emissions, as could be assumed based on the much longer detours that vehicles would now routinely take to reach their destination. Instead, a slight decrease was observed – from a median of approx. 1755 g per vehicle and a total of 3780 kg to a median of 1679 g and total of 3740 kg. This is also indicative of a smoother traffic flow.



(a) Downlink to vehicles

(b) Uplink to TIC

Figure 9: Impact of the CoCar communication system on network traffic

6.2. Impact on Network Traffic

Aside from the impact the CoCar communication system might have on road traffic, it is just as important to know how the rollout of such a system would affect existing services – in particular with regard to the allocation of bandwidth to the CoCar system. As the availability of MBMS and, hence, a multicast message dissemination service, was expected to have a large impact on system load and delays, the following evaluations have been performed for two different parameter sets each, modeling a system with and without MBMS capability.

Figure 9 illustrates the impact of the CoCar system on network traffic – both in the core network and on the air interface. Figure 9a shows an example of the bandwidth used by the CoCar system depending on the system configuration, plotted as a CDF of the number of bytes sent by the TIC to the core network within 10 s intervals. As can be expected, the relations between message size, carousel size, and allocated maximum bandwidth lead to a bursty traffic pattern. In the unicast case, network load was heavy, peaking regularly at approx. 7000 kbit/s with the typical system load still exceeding approx. 2000 kbit/s. In a system with MBMS capabilities, the median of network load yielded a much lower 2.5 kbit/s and peak system load was at only 6 kbit/s.

Figure 9b displays a similar plot, but illustrates the number of bytes sent by all CoCar clients via the air interface, i.e. on the RACH. Here, client-side duplicate avoidance lead to a sparser utilization of the available channel, with bandwidth utilization in a unicast-only system remaining below 300 kbit/s and, more importantly, utilization of the MBMS-capable system peaking at under 0.2 kbit/s and a median value near 0 kbit/s.

Extrapolating these results for a nationwide communication system, even when keeping in mind that the measures recorded in this simulation only reflect the quantity of data transmitted for an area of less than 10 km × 10 km, these figures appear promising. In the end, most of the accumulated data is only relevant for the area it was recorded in and, given appropriate infrastructural support, need not be transmitted globally.

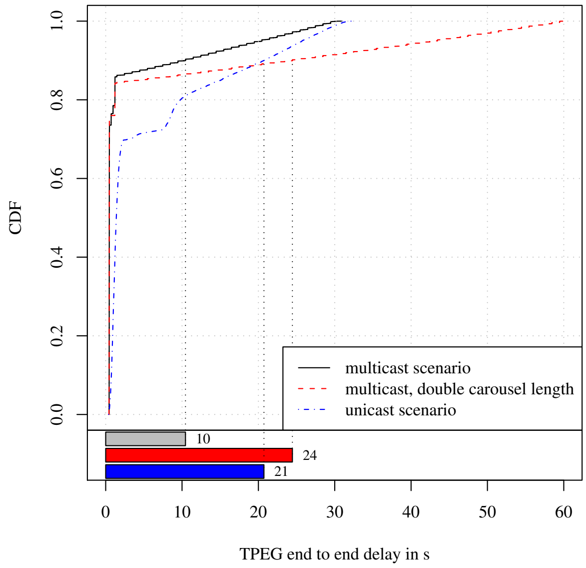
6.3. End-to-End Delays

From an end user perspective, one of the most important measures to be recorded for the CoCar communication system is that of end-to-end delays. Often, the end-to-end delay is the one key figure that determines whether certain applications are feasible in a system – or if they simply cannot be realized because information would not reach its addressees in time.

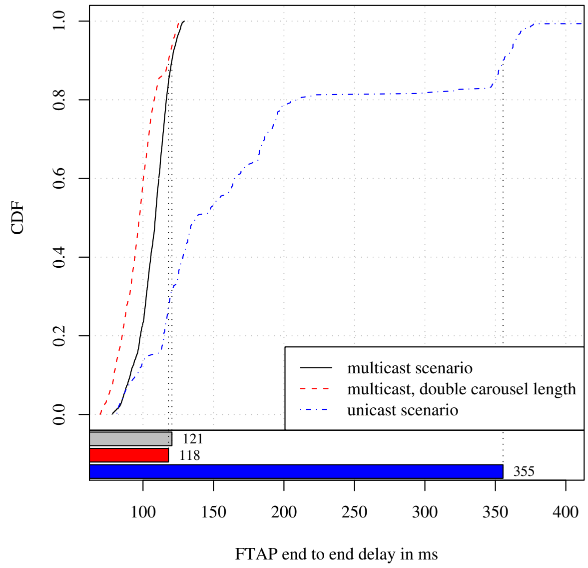
These measures are plotted in Figure 10 for the TPEG and FTAP message types and for three different parameter sets.

Again, the first parameter set represented a communication system incapable of performing MBMS services. The second and third parameter sets both model an MBMS-capable system and illustrate the trade-off between on the one hand reducing delay in the direct vicinity of traffic incidents, and on the other hand increasing the delay that wide-range dissemination of information will suffer.

Figure 10a displays the delay between a warning message being sent by one vehicle and its associated TPEG traffic information message being received by another. Not



(a) Messages via TPEG



(b) Messages via FTAP

Figure 10: End-to-end delay of CoCar messages, depending on the means of delivery

counted is the time for cars that have not yet entered the simulation area and are as such fundamentally unable to receive any message. Also explicitly not reflected in this figure are messages containing information that was already known to cars, e.g. because they had been received via FTAP by the time a TPEG message was received.

For the first parameter set, a system performing only unicast transmissions of messages in the downstream, noticeable end-to-end delays were experienced by most vehicles, with delays of up to 21 s for the best 90 % of transmissions. For an MBMS-enabled system, however, 90 % of messages could be seen to have experienced end-to-end delays of under 10 s with 75 % of messages experiencing no more than a 1 s delay. Still, even in this case for 10 % of messages it took up to one complete carousel repetition interval until they were received by all vehicles. In the baseline scenario, this means that messages may take up to slightly over 30 s, in the case of doubled warning intervals slightly over 60 s, until wide-area dissemination of a message is complete.

Similarly, Figure 10b displays the delay between a warning message being sent by one vehicle and the re-sent FTAP message being received by vehicles in the same cell. Once again, this measure only includes transmissions for cars that had already entered the simulation area and which had already been informed about the particular congestion.

While results for an MBMS-incapable system do not appear very promising for full-scale deployment of services, with the 90 % quantile of messages experiencing a near-field communications delay of over 350 ms, optimal parameterization of an MBMS system could be shown to result in average delays of approximately 100 ms and in both evaluated parameterizations a 90 % quantile of under 125 ms was achieved – both are values which are well under the human reaction time.

6.4. Application Message Processing in the TIC

The data traffic load offered to the TIC is calculated based on the application and road traffic models. The simulation encompasses over 2000 moving vehicles which are sending traffic messages, so that a CoCar TPEG application message is forwarded every second to the TIC. According to the designed CoCar applications, the estimated message size is 1541 bytes in XML. Evaluation of the offered data traffic throughput resulted in a maximum value of around 24 Mbit/sec and a mean value of 15.7 Mbit/sec.

As the operation of XML parsing is computational expensive, the first comparison concerned the processing capabilities of three distinct XML parsing approaches, DOM, SAX and JAXB. Measurements were taken in the same hardware and software environments. In order to avoid unstable states, the test system has a 180 s ramp up time and a 30 s ramp down time. In each test, the XML parser performed transactions for 300 s. One transaction is the parsing process of an XML-formatted TPEG application message. This way we calculated the processing throughput.

The comparison results show that the SAX parser has the highest processing speed of these three parsers, since it is a streaming push parser that only scans through the whole XML document once. SAX is able to achieve a throughput of about 30 Mbit/s. Unfortunately, no modifications of the XML document are allowed by the SAX parser. However, the designed CoCar TIC not only accesses the XML document content but also needs to modify the content fields and to add server information to the received messages. In contrast, the DOM and the JAXB approaches provide the possibility to modify the XML formatted messages, however, their average processing speed is around 0.32 Mbit/s, much lower than the offered data traffic load of 15.7 Mbit/s [19].

7. Conclusion

Based on a proof-of-concept study, we presented in this paper a comprehensive simulation framework to help in the design and evaluation of upcoming, UMTS-based C2I communication systems. Such 3G approaches might complement recent efforts to establish VANET-based Intelligent Transportation Systems such as TIS applications – basically because they are already widely deployed and provide capabilities such as inherent security measures and low latency communication independent of the current traffic density. Both are needed in the intended scenario. The simulative evaluation is not limited by currently implemented UMTS infrastructure and thus able to use forthcoming technologies. We described in detail the individual models our simulations were composed of and how these models interacted to form the framework.

The study demonstrated the capabilities of such an UMTS-based C2I communication system. The results of the performed evaluation indicate much lower delay times and a much lighter network load than can be achieved with currently-implemented UMTS infrastructure. Bringing about an almost unnoticeable use of uplink capacity, the proof-of-concept evaluation of a C2I communication system using optimally-parameterized MBMS yielded near-field communications delays of well under the human reaction time. Moreover, wide-area delays in the system still easily surpassed those of conventional C2C communication systems. The performance analysis of application message processing in the TIC indicates that the challenges in UMTS-based C2I communication system exist not only in the communication networks, but also in the TIC where application messages are collected and processed. Moreover, the deployment of the planned TIS could be shown to have no negative impact on the environment. In fact, calculated emission levels were even lower while the TIS was active.

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References

[1] Wireless Access for Vehicular Environments, Draft Standard 802.11p-D4.0, IEEE (2008).

[2] A. Boukerche, H. Oliveira, E. Nakamura, A. Loureiro, Vehicular Ad Hoc Networks: A New Challenge for Localization-Based Systems, Elsevier Computer Communications 31 (12) (2008) 2838–2849.

[3] C. Lochert, B. Scheuermann, C. Wewetzer, A. Luebke, M. Mauve, Data Aggregation and Roadside Unit Placement for a VANET Traffic Information System, in: 5th ACM International Workshop on VehiculAr Inter-NETworking (VANET 2008), ACM, San Francisco, CA, 2008, pp. 58–65.

[4] L. Wischhof, A. Ebner, H. Rohling, Information dissemination in self-organizing intervehicle networks, IEEE Transactions on Intelligent Transportation Systems 6 (1) (2005) 90–101.

[5] J. Santa, A. Moragon, A. F. Gomez-Skarmeta, Experimental evaluation of a novel vehicular communication paradigm based on cellular networks, in: IEEE Intelligent Vehicles Symposium (IEEE IV 2008), 2008, pp. 198–203.

[6] D. Valerio, F. Ricciato, P. Belanovic, T. Zemen, UMTS on the Road: Broadcasting Intelligent Road Safety Information via MBMS, in: 67th IEEE Vehicular Technology Conference (VTC2008-Spring), 2008, pp. 3026–3030.

[7] M. Raya, J.-P. Hubaux, The Security of Vehicular Ad Hoc Networks, in: 3rd ACM Workshop on Security of ad hoc and Sensor Networks, Alexandria, VA, USA, 2005, pp. 11–21.

[8] P. Gupta, P. Kumar, The Capacity of Wireless Networks, IEEE Transactions on Information Theory 46 (2) (2000) 388–404.

[9] F. Zijderhand, J. Biesterbos, Functions and applications of SOCRATES: a dynamic in-car navigation system with cellular-radio based bi-directional communication facility, in: 1994 Vehicle Navigation and Information Systems Conference, Yokohama, Japan, 1994, pp. 543–546.

[10] S. Y. Baek, Y.-J. Hong, D. K. Sung, Adaptive Transmission Scheme for Mixed Multicast and Unicast Traffic in Cellular Systems, IEEE Transactions on Vehicular Technology 58 (6) (2009) 2899–2908.

[11] C. Pinart, P. Sanz, I. Lequerica, D. Garcia, I. Barona, D. Sánchez-Aparisi, DRIVE: a reconfigurable testbed for advanced vehicular services and communications, in: 4th International Conference on Testbeds and Research Infrastructures for the Development of Networks & Communities (TRIDENTCOM 2008), Innsbruck, Austria, 2008.

[12] K. Collins, G.-M. Muntean, A vehicle route management solution enabled by Wireless Vehicular Networks, in: 27th IEEE Conference on Computer Communications (IEEE INFOCOM 2008): Mobile Networking for Vehicular Environments (IEEE MOVE 2008), Poster Session, Phoenix, AZ, 2008.

[13] J. Alcaraz, G. Pedreao, F. Cerdán, J. Garcia-Haro, Simulation of 3G DCHs Supporting TCP Traffic: Design, Experiments and Insights on Parameter Tuning, in: 1st ACM International Conference on Simulation Tools and Techniques for Communications, Networks and Systems (SIMUTools 2008): 1st ACM International Workshop on OMNeT++ (OMNeT++ 2008), ACM, Marseille, France, 2008.

[14] C. Sommer, Z. Yao, R. German, F. Dressler, On the Need for Bidirectional Coupling of Road Traffic Microsimulation and Network Simulation, in: 9th ACM International Symposium on Mobile Ad Hoc Networking and Computing (ACM Mobihoc 2008): 1st ACM International Workshop on Mobility Models for Networking Research (MobilityModels 2008), ACM, Hong Kong, China, 2008, pp. 41–48.

[15] C. Sommer, F. Dressler, Progressing Towards Realistic Mobility Models in VANET Simulations, IEEE Communications Magazine 46 (11) (2008) 132–137.

[16] C. Sommer, Z. Yao, R. German, F. Dressler, Simulating the Influence of IVC on Road Traffic using Bidirectionally Coupled Simulators, in: 27th IEEE Conference on Computer Communications (IEEE INFOCOM 2008): Mobile Networking for Vehicular Environments (IEEE MOVE 2008), IEEE, Phoenix, AZ, USA, 2008, pp. 1–6.

[17] C. Sommer, A. Schmidt, R. German, W. Koch, F. Dressler, Simulative Evaluation of a UMTS-based Car-to-Infrastructure Traffic Information System, in: IEEE Global Telecommunications

Conference (IEEE GLOBECOM 2008), 3rd IEEE Workshop on Automotive Networking and Applications (AutoNet 2008), IEEE, New Orleans, LA, 2008.

[18] U. Dietz (ed.), CoCar Feasibility Study: Technology, Business and Dissemination, Public report, CoCar Consortium (May 2009).

[19] Y. Chen, G. Gehlen, G. Jodlauk, C. Sommer, C. Görg, A Flexible Application Layer Protocol for Automotive Communications in Cellular Networks, in: 15th World Congress on Intelligent Transportation Systems (ITS 2008), New York City, NY, 2008.

[20] Transport Protocol Expert Group, Traffic and Travel Information (TTI) - TTI via Transport Protocol Experts Group (TPEG) Extensible Markup Language (XML), TS 24530, ISO (April 2006).

[21] A. Varga, The OMNeT++ Discrete Event Simulation System, in: European Simulation Multiconference (ESM 2001), Prague, Czech Republic, 2001.

[22] 3GPP, Physical channels and mapping of transport channels onto physical channels (FDD), TS 25.211 v7.3.0, 3rd Generation Partnership Project (3GPP) (2008).

[23] 3GPP, Physical layer procedures (FDD), TS 25.214 v7.2.0, 3rd Generation Partnership Project (3GPP) (2006).

[24] 3GPP, User Equipment (UE) radio transmission and reception (FDD), TS 25.101 v7.6.0, 3rd Generation Partnership Project (3GPP) (2006).

[25] A. Mahajan, N. Potnis, K. Gopalan, A. Wang, Urban Mobility Models for VANETs, in: 2nd IEEE International Workshop on Next Generation Wireless Networks 2006 (IEEE WoNGeN 2006), Bangalore, India, 2006.

[26] D. Krajzewicz, G. Hertkorn, C. Rössel, P. Wagner, SUMO (Simulation of Urban MObility); An open-source traffic simulation, in: 4th Middle East Symposium on Simulation and Modelling (MESM2002), Sharjah, United Arab Emirates, 2002, pp. 183–187.

[27] S. Krauß, P. Wagner, C. Gawron, Metastable states in a microscopic model of traffic flow, Physical Review E 55 (1997) 5597–5602.

[28] A. Cappiello, I. Chabini, E. Nam, A. Lue, M. Abou Zeid, A statistical model of vehicle emissions and fuel consumption, in: 5th IEEE International Conference on Intelligent Transportation Systems (IEEE ITSC), 2002, pp. 801–809.

[29] C. Sommer, R. Krul, R. German, F. Dressler, Emissions vs. Travel Time: Simulative Evaluation of the Environmental Impact of ITS, in: 71st IEEE Vehicular Technology Conference (VTC2010-Spring), Taipei, Taiwan, 2010.

[30] R Development Core Team, R: A language and environment for statistical computing, Report, R Foundation for Statistical Computing, Vienna, Austria (2008).