Cooperative Driving in Mixed Traffic with Heterogeneous Communications and Cloud Infrastructure

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Keywords: Cooperative Driving, Mixed Traffic, Hybrid Communication, HMI Design, Modular System Concept, ITS-G5, C-V2X, Cloud Computing.

Abstract: In this paper we introduce an Intelligent Transport System (ITS), designed for enabling cooperative driving manoeuvres in mixed traffic scenarios considering heterogeneous communications and cloud infrastructure systems. We present an architecture that enables connected vehicles to access ITS services independent of their underlying communication technology. This is achieved by introducing a large scale communication system including the road-side infrastructure as well as a heterogeneous cloud. We present insights from the Automated Connected Vehicle (ACV) concept and examine human factors elaborating on the experience of two aspects: driving in an ACV as well as driving in a Non-Automated Connected Vehicle (NACV), interacting with an ACV. Furthermore, we present insights of initial demonstrations, emphasizing that the system works well in real traffic scenarios.

1 INTRODUCTION

Automated driving is in the focus of recent research and development activities in the ITS community, but also highly present in the media, especially w.r.t. its target expansion: fully autonomous vehicles. Modern communication technologies are seen as one of the main enabler for realizing safety, comfort, and economic goals, especially in more complex urban traffic scenarios (Hobert et al., 2015). Since the introduction of automated driving is going to be a gradual process, the majority of the vehicles will not be equipped with automation technology for several years. Especially for such mixed traffic scenarios, inter-vehicle communication is crucial for a seamless integration of automated vehicles. On the one hand inter-vehicle communication in combination with advanced Human-Machine-Interfaces (HMIs) can support human drivers in conventional cars by understanding the behaviour of automated vehicles, which can differ from conventional driving behaviours in specific situations. On the other hand, communication could also help the automated vehicle to react on human driven cars more sensible and foresighted (Zhang, 2018). In addition to improving acceptance for Automated Connected Vehicle (ACV), communication also supports cooperative manoeuvres between ACV and Non-Automated Connected Vehicle (NACV), which can help to avoid critical situations and unnecessary congestions that arise in everyday traffic.

In order to support vehicles and human drivers in their decision process, the infrastructure plays a major role, e.g., to give neutral recommendations to particular vehicles or groups of vehicles. While the advantage of communication is undisputed, the choice

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Auerswald, R., Busse, R., Dod, M., Fritzsche, R., Jungmann, A., Klöppel-Gersdorf, M., Krems, J., Lorenz, S., Schmalfuß, F., Springer, S. and Strobl, S.
Cooperative Driving in Mixed Traffic with Heterogeneous Communications and Cloud Infrastructure.
DOI: 10.5220/0007682900950105
In *Proceedings of the 5th International Conference on Vehicle Technology and Intelligent Transport Systems (VEHITS 2019)*, pages 95-105
ISBN: 978-989-758-374-2

of the actual technology is subject to lively discussions and a clear prospect of a preferred technology exchanging ITS information is missing. Protocols and messages designed for exchanging information among vehicles as well as among vehicles and the infrastructure are based on direct communication (Festag, 2014). While there is a competitive situation for direct Vehicle-to-Everything (V2X) communication technologies between IEEE 802.11p and Cellular V2X (C-V2X), conventional cellular is already implemented in about one third of today's vehicles (Statista, 2018). Hence, some researchers (Hameed Mir and Filali, 2014; Cecchini et al., 2017) see advantages in using current cellular systems, at least for a transition period.

In this work, we focus on cooperative manoeuvres among ACVs and NACVs supporting heterogeneous communication technologies as well as a heterogeneous cloud infrastructure.

This paper is structured as follows: First we present the system concept by introducing the overall architecture as well as an exemplary use case. We give more insights in Sections 3, 4, and 5, by presenting the communications system, the infrastructure and the vehicle side, respectively. We show an overview of a first live demonstration in Section 6, before we conclude the work in Section 7.

2 SYSTEM CONCEPT

In the presented system setup, three major components are considered: the vehicle, the infrastructure, and the communication system. The latter connects vehicles with each other as well as the vehicles with the infrastructure. The unique feature of the system concept is the integration of heterogeneity w.r.t. all three components. On the vehicle side, ACVs and NACVs are considered, while for the infrastructure side a cloud at the Road-Side Units (RSUs) as well as a central cloud is taken into account. The exchange of ITS messages is based on either direct Device-to-Device (D2D) communications (e.g. 802.11p, C-V2X), or cellular uplink/downlink communications.

2.1 Architecture

The overall architecture is illustrated in Figure 1. On the vehicle side the ACV (blue) can execute its manoeuvres fully automated, while it might be beneficial to inform the passenger about driving decisions. On the other side, the driver of the NACV (grey) should be informed about manoeuvres of the ACV, especially

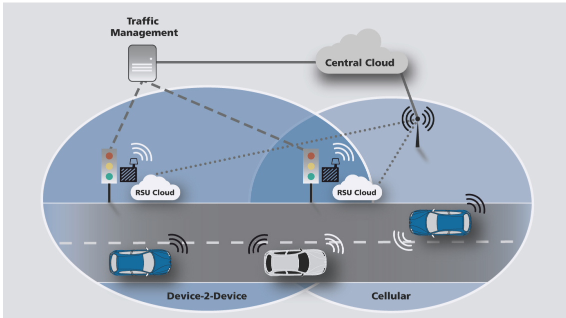

Figure 1: Overall system architecture.

about those not typical for conventional traffic situations. The cooperation of ACV and NACV is of special interest in this work. A specific use case is described in more detail in the next section.

All vehicles, independent of their degree of automation, can be equipped either with direct communication units or with both, direct and cellular communication units. Note, that vehicles equipped with D2D units only, are not considered in this work (cellular is typically assumed for connectivity to the public key infrastructure as well as the central cloud).

The vehicles are not just communicating with each other, but also with the infrastructure in order to obtain information about, e.g., traffic light phases or receive support for driving decisions. The heterogeneously equipped vehicles are supported by a heterogeneous infrastructure. Hence, services provided by the RSU clouds via direct D2D communication can also be provided by the central cloud via cellular communication. Moreover, the communication among vehicles is supported by a geographical messaging service, which allows distributing messages via the cellular uplink-downlink in a particular region.

2.2 Use Cases

While a number of cooperative driving use cases are discussed in the ITS community, we only consider a selected subset of manouvres as shown in Figure 2.

For the remainder of this section, we focus on the cooperative turn as an example, as it makes use of a broad set of architectural features. The scenario consists of an intersection, potentially equipped with traffic lights, while the two main actors are an NACV (grey vehicle) and an ACV (blue vehicle), both approaching the intersection from opposite directions. The traffic light is passed based on Green-Light Optimized Speed Advisory (GLOSA) (Kloeppel et al., 2019). At the intersection, the NACV intends to turn left, but needs to wait for the ACV. We assume that there are other vehicles behind both cars (dark grey vehicles), which makes the situation more relevant,

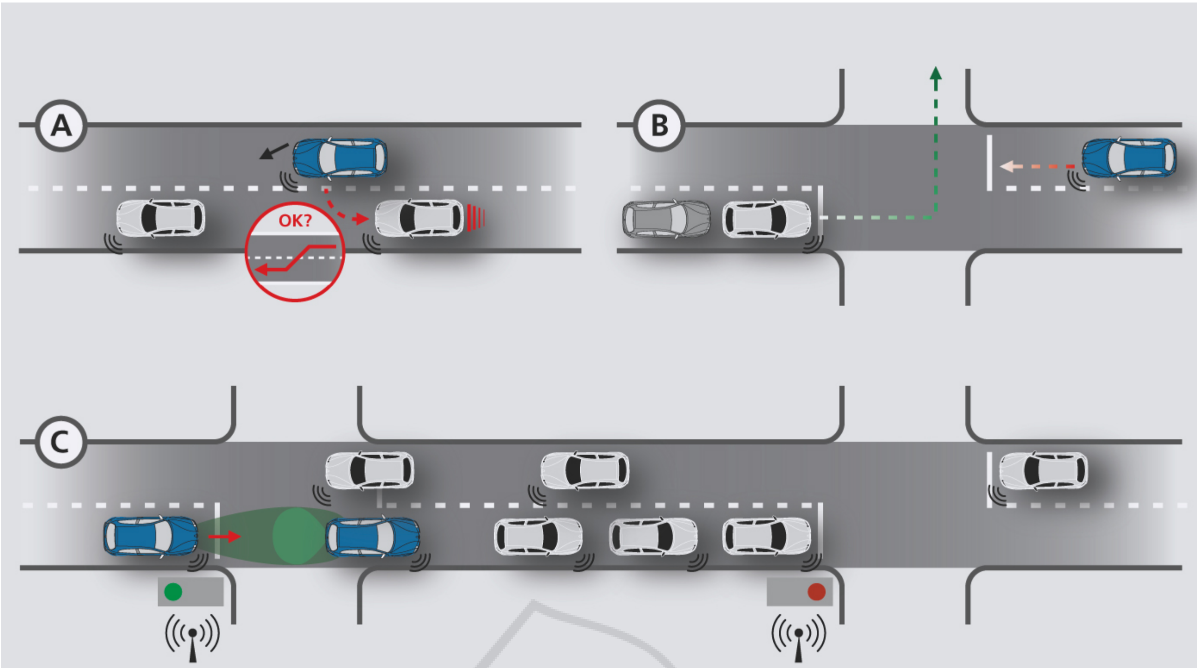

Figure 2: Example use cases of automated and connected driving: (A) cooperative lane change manoeuvres, (B) cooperative turn, (C) predictive intersection crossing and traffic light approaching for blocked flow-offs.

due to a noticeable delay for the NACV and all following vehicles.

In order to avoid a blocking, the ACV can cooperate by giving up its right of way. Based on communication between the two vehicles but also with support from the infrastructure, the NACV recognizes the ACV's willingness to cooperate and passes the crossing. For that purpose, we introduce two new message types. The Maneuver Coordination Message (MCM) is transmitted form vehicles in order to inform about planed and ongoing manoeuvres but also request manoeuvres from other vehicles. The message is currently studied in ETSI ITS standardization, where several approaches are discussed. Based on the MCM, we introduce the Maneuver Recommendation Message (MRM), sent out from the infrastructure side, in order to support vehicles in their driving decisions.

Based on the cooperative turn, the mean delay (w.r.t. all involved vehicles) is assumed to be reduced substantially. Hence, with a large penetration of cooperatively behaving vehicles, traffic flow can be increased. In the following sections, we show how the cooperative turn can be implemented in a practical system, incorporating heterogeneous communication and cloud technologies.

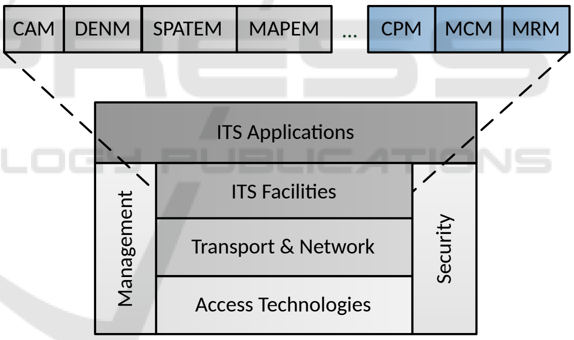

Figure 3: ITS communication stack.

3 COMMUNICATIONS

Information exchange among vehicles but also among vehicles and the infrastructure is subject to standardisation activities at several international committees, e.g., ETSI, IEEE or SAE. A common view on communications in ITS is given by the principle stack design, illustrated in Figure 3. In this paper, the focus w.r.t. communications is on ITS facilities messages as well as on access technologies. The messages utilized in this paper are based on ETSI ITS-G5, see, e.g., (ETSI EN 302 637-2 V1.3.2 (2014-11), 2014).

Even though ITS facilities have been primarily designed assuming IEEE 802.11p as access technology, the protocol layer is reused for C-V2X and is also discussed for cellular-based data exchange, e.g., at 5GAA (5GAA, 2018). Note that for transport and network layer we assume Basic Transport Protocol (BTP) (ETSI EN 302 636-5-1 V2.1.1 (2017-08), 2017) plus geo-networking (ETSI EN 302 636-4-1 V1.3.2 (2017-08), 2017) for D2D, and TCP/IP with geo-based addressing for cellular communications.

3.1 ITS Facilities Messages

Basic messages of ETSI ITS facilities have been used for enabling day 1 and day 1.5 use cases (C-ITS Platform, 2016). Such messages are, e.g., the Cooperative Awareness Message (CAM), Decentralized Environmental Notification Message (DENM), Signal, Phase and Timing Extended Message (SPATEM) and the Map Extended Message (MAPEM). On top of the basic set, we integrate advanced messages, currently under investigation and subject to an ongoing standardization process in ETSI ITS. The Collective Perception Message (CPM) enables to transmit dynamic object information gathered from sensors located in the vehicle or at the infrastructure side.

For realizing cooperative manoeuvres, however, a more dedicated information exchange needs to be established. For this reason, MCM and MRM have been designed and integrated into the system. Both formats are used for realising the cooperative turn. Even though the details of the message format are beyond the scope of this paper, the basic idea and message flow is explained in the following.

The NACV sends out an MCM with its short-term route information (based on the navigation system) and the intention to turn left (based on the turn-left signal). Note, that the route information is optional. The ACV recognizes the intention of the NACV by receiving a MCM. Moreover, it receives a CPM from the infrastructure, informing about the overall traffic situation. This might include non-connected road users, detected by road-side sensors. The blue vehicle realises the overall gain of cooperation and decides to let the NACV pass. In order to inform the NACV about this decision, the ACV sends an MCM including two main information. First, the ACV's ego intention of decelerating a certain amount (for letting the NACV pass) and secondly a request to the NACV to pass the intersection in a certain time.

In addition to that, the infrastructure can support both vehicles. As a basic service, the infrastructure is sending out SPATEM and MAPEM in order to let both vehicles perform GLOSA. On top of that, the MRM is utilized to support both, the ACV and the NACV. The ACV can receive the recommendation to initiate a cooperative turn, while the NACV can receive a recommendation to cooperate with ACV and pass the intersection as requested. The concept of MCM and MRM presented in this paper includes the possibility to communicate a cause of an intention, request or recommendation. One of the various causes can be a reference on another intention, request, or recommendation. Based on this concept, unambiguous coordination is possible.

3.2 Access Technologies

Access technologies for communication in ITS is a well-studied field for several years. However, the right choice of technology is still subject of current discussions.

3.2.1 Direct Communication

The development of a direct Vehicle-to-Vehicle (V2V) communication technology has been motivated by the independence of the availability of a managed infrastructure, like the cellular system. On that basis, the direct communication system IEEE 802.11p has been standardized, which supports higher vehicle speeds, works without any initialization procedures and is based on broadcasting information towards road users in the surrounding. While the IEEE 802.11p is available for several years, an alternative standard for V2X communication has been developed and integrated into the 3GPP standard. It allows exchanging information directly among road users, similar to IEEE 802.11p, but based on the cellular frame structure. Hence, it is also referred to as C-V2X. The two direct communication systems are in a competing situation, while it is not clear at the moment which technology is going to be used in which region, or if a coexistence of both technologies is realistic.

In the presented system architecture both direct access technologies are integrated, i.e., ITS messages can be transmitted via 802.11p, C-V2X, or both. Note that it is technically not possible to receive a message via C-V2X, which has been send via 802.11p and vice versa. However, if differently equipped vehicles are in the surrounding, ITS-messages need to be transmitted via cellular in parallel. For such situations, the infrastructure supports to achieve that vehicles with different direct communication technologies recognize each other.

3.2.2 Cellular Communication

Even though direct communication clearly has its advantages, e.g., in an efficient spectrum usage and lower latencies, the penetration of vehicles equipped with this technology in real traffic tends to zero. Although several car manufacturers announced an integration of 802.11p or C-V2X in series-production vehicles starting in 2019, the penetration rate will stay low for several years. However, the number of cars, equipped with cellular is markedly higher. Even without cellular integrated in a vehicle itself, an upgrade (e.g., cellular based HMI) is less costly compared to today's available direct-2-device units.

The presented architecture allows interaction among vehicles and traffic infrastructure independent of the used communication technology. Messages can either been forwarded via geo-based addressing (GeoMessaging) or infrastructure services can be utilized via the central cloud.

4 INFRASTRUCTURE

Beside the communication among vehicles itself, a key aspect are the ITS services provided by the infrastructure. In the presented system, we extend basic infrastructure-services (e.g., via SPATEM) by collective perception service via CPM as well as recommendations via MRM in order to support cooperative manoeuvres and foresighted driving. Due to the heterogeneous communication technologies also a heterogeneous cloud infrastructure is established for providing services for both, vehicles equipped with direct communication and those equipped with cellular. While direct communication based services can be provided by the RSU cloud, cellular users primarily refer to the central cloud. Note that RSU cloud usage is also possible for cellular users via geo-messaging. For the following discussions cellular means Long Term Evolution (LTE).

4.1 RSU Cloud

The system concept of the RSU cloud is modular and hybrid. It consists of various communication interfaces (like 802.11p and LTE), the ITS facilities and the central element the hybrid communication unit, which separates the ITS facilities from the communication interfaces and the software stack of the RSU cloud. The hybrid communication control handles the distribution and reception of the messages. So it is possible to send one message parallel over more than one communication interface. On the other hand all the received messages will be forwarded to the facilities-layer, no matter from which interface they were received. With this concept it is possible to reach more road users over various communication technologies, or achieve a safer transmission by using redundant paths.

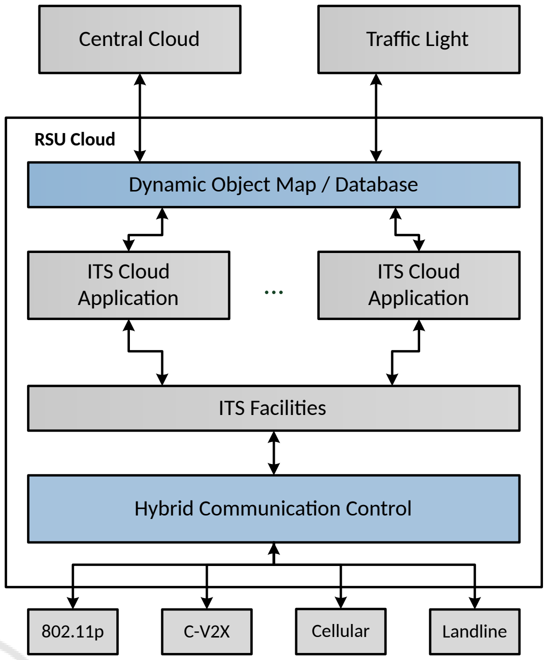

Figure 4: System concept of RSU cloud.

The current system concept of the RSU cloud consists of various communication interfaces to enable different applications. The LTE interface realizes the connection to the backbone. Furthermore, this interface is used to distribute messages to all vehicles in region via GeoMessaging. The two interfaces 802.11p and C-V2X are used to directly communicate with the road user.

All the ITS applications run in Docker-Containers (Rad et al., 2017) so that they are separated from each other. This strengthens the safety and security, facilitates the roll out of the software components, and makes them independent from the hardware. This concept enables different partners to run their own applications on the RSU cloud without causing interference to other applications (see (Salahuddin et al., 2014) for an analysis from the resource management point of view). Each ITS application could subscribe for messages and information from the ITS-Facility-Layer and from the Dynamic Object Map (DOM) to realise their services. The RSU cloud, namely a NVIDIA® Jetson™ TX2, is a computation unit which contains a GPU to support parallel computation and AI algorithms.

Figure 4 shows the system concept of the RSU cloud. Components that are also used in the central cloud are marked grey. The components that are unique to the RSU cloud are marked blue. Due to the modular structure the concept is future-proof. Not further supported interfaces can be easily replaced by new state of the art interfaces or additional interfaces can be added. It enables the simulcast operation for backward compatibility. The software stack in the RSU cloud shares the concept of modularity already found in the hardware layout. It consists of a number of micro services, which communicate using gRPC (Google, 2018).

This approach offers flexibility for future extensions and allows to quickly exchange single components, e.g., for bug fixing or version updates. The core system is the DOM, which stores static (e.g. maps) and dynamic (e.g. vehicle positions, traffic light state) information. Data ingress happens through ITS messages (especially CAM, CPM) as well as backend systems (e.g., prognoses for traffic lights) and the TLS (current traffic light state). Before information is passed into the DOM, there is an additional step of data fusion and validation. This step ensures that only valid entries are inserted and objects, which were detected by more than one method (e.g. via its own CAM and the CPM of another vehicle), are inserted only once. Data egress mainly concerns the generation of MAPEM and SPATEM and the communication with backend systems as described above. Additionally, the information stored in the DOM can be used to generate manoeuvre recommendations (e.g., lane change), which are broadcast using the MRM.

4.2 Central Cloud

In addition to the decentralized cloud environments provided by the individual RSUs, we also consider the usage of a centralized cloud-based solution, termed central cloud in the scope of this project. A high-level view of the architecture is provided in Figure 5, where the components specific to the central cloud are highlighted in blue.

While the services provided via the central cloud address the same ITS applications as the RSU, there are some key differences. The only communication channel between the connected vehicles and the cloud services is provided by a cellular data connection. In order to evaluate different communication schemes, two distinct means of transporting ITS messages via the cellular connection are supported. For the first scheme, a TCP/IP connection providing the transport layer for the standardized communication protocol MQTT (ISO/IEC 20922:2016, 2016) is established to a central message broker deployed as part of the central cloud in order to transport the ITS messages between the communicating parties. The messages are routed by the message broker according to a topic-based publish-subscribe pattern. Alternatively,

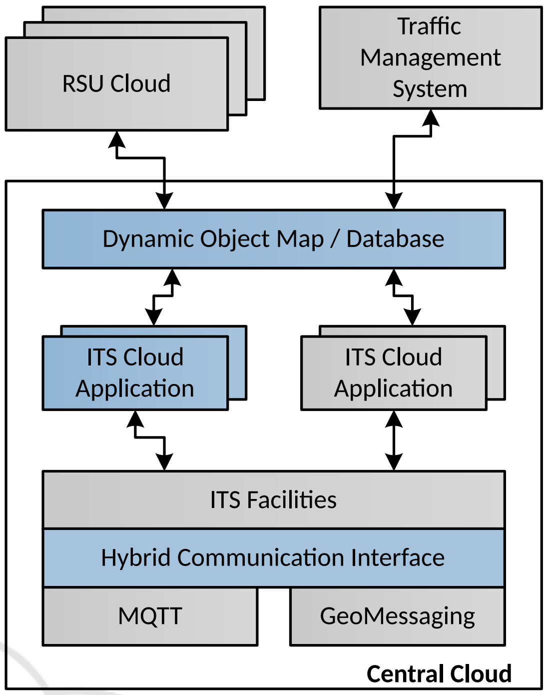

Figure 5: Architecture of the central cloud.

in order to allow for an efficient and scalable communication without a central message broker, a GeoMessaging solution, implemented by means of IPv6 multicast, which is deployed in the core of the cellular network, is used. The interface between the communication channels and the applications is provided by the ITS facilities layer, which allows for a complete decoupling of the mode of communication from the actual ITS applications.

The individual services deployed on the central cloud platform are implemented as micro-services and are coupled via a high-performance messaging bus and gRPC APIs (Google, 2018). Due to the more centralized nature of the central cloud, the ITS applications deployed have a larger pool of information available, as information is ingested from a wider geographical region. Specifically, the central cloud services are connected to all equipped vehicles and RSUs in the target area. This allows the ingestion of real-time data provided by the RSUs, including the status of the traffic lights and sensor data. Additional information is made available via the Traffic Management System (TMS) of the city of Dresden, VAMOS (Krimmling, 2014). The TMS provides predictions for both the signal state and the delay for each signal at the relevant intersections. This information is pushed from the TMS to the respective service in the central cloud using the well-established DATEX II (CEN/TC 278, 2018) interface. The information provided by the various sources is combined into a coher-

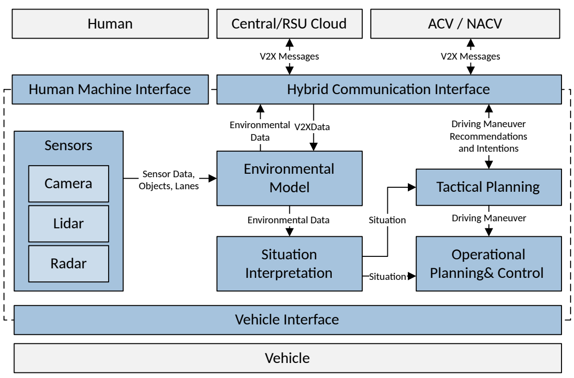

Figure 6: Automated Driving System (ADS) and its integration into the overall architecture.

ent dynamic object map and, after fusion with static information such as HD maps, provides the basis for the ITS applications. The messages generated by the cloud applications are processed by the ITS facilities and, either via cloud-based MQTT or GeoMessaging, transmitted to the connected vehicles. The messages generated by the vehicles take the reverse path and are forwarded to the appropriate cloud application, based on the type of the message and other factors such as the location of the originating vehicle.

5 VEHICLES

Cooperative driving in real traffic cannot be accomplished by focusing on automated vehicles alone. In our work, we consider both automated and non-automated vehicles and assume that all entities are connected and share information.

5.1 Automated Connected Vehicle (ACV)

Each ACV implements an ADS that enables the vehicle to operate without intervention of a human driver in a defined Operational Design Domain (ODD). Briefly speaking, an ODD defines environmental and time-of-day conditions and restrictions, respectively, the presence or absence of certain traffic, and roadway characteristics. Furthermore, in order to facilitate cooperation during dynamic driving tasks, each ADS is embedded into the overall architecture, as presented in Section 2.1. That is, each ADS can rely on information from other ACVs as well as NACVs while simultaneously providing information such as driving manoeuvre intentions or sensor objects to both other traffic participants and infrastructure services. Figure 6 gives a broad overview of the implemented ADS and its integration into the overall architecture. The dashed line indicates the boundary of the ADS. Three components serve as main input for the system: sensors, the human machine interface (cf. Section 5.2) and the hybrid communication interface. Sensor data, such as camera images, radar objects, lidar point clouds, or even positioning data is essential to create a local view of the surrounding environment. The ego-centric environmental model includes host data from the vehicle interface as well as relative sensor data (e.g., dynamic objects or lanes). Furthermore, it incorporates world data such as static map data and dynamic environment data (e.g., accidents or traffic light status) from the hybrid communication interface. As discussed in Section 3 and 4, the hybrid communication interface allows for vehicle to vehicle, vehicle to infrastructure, as well as vehicle to backend communication. Finally, as different sources possibly provide information about the same objects, object data is fused on a fine-grained level. The environment model's data is used to interpret situations and to select and plan abstract manoeuvers. The situation interpretation is necessary to detect possibly hazardous situations, to obey traffic regulations, or to optimize other metrics such as long-term fuel consumption.

Depending on the current situation, a tactical planner is subsequently selecting and planning abstract driving manoeuvers such as lane changes, speed adjustments, or even parking manoeuvers. For cooperation, the tactical planner simultaneously takes MRMs from the infrastructure as well as MCMs from other traffic participants into account. Due to their abstract nature, manoeuvers are not directly realizable by car actuators. For that reason, an operational planner translates the current driving manoeuvere into time-dependent trajectories. A control component finally subdivides the trajectory into multiple control sequences for the vehicle interface. More concretely, it computes throttle and brake commands as well as the steering angle for the car actuators. The ADS provides two levels of output: local and environmental output. Local output refers to the interaction with the driver of the vehicle via HMI (e.g., by visualizing the next planned manoeuvre). Furthermore, it refers to the control of the vehicle via the previously introduced vehicle interface. Environmental output refers to the provision of data via the hybrid communication interface to the environment. That is, parts of the local view of the host are transmitted in terms of the following ITS messages:

- CAMs for host data (position, acceleration, etc.),
- CPMs for detected dynamic objects, and
- MCMs for coordinating manoeuvers with other traffic participants.

In order to implement the cooperative turn discussed earlier, the NACV and ACV exchange MCM messages and rely on CAM information. For NACV there is no vehicle controlling component. However, the communication and HMI parts (the upper part of Figure 6) are equivalent to the ACV architecture. More insights on HMI design for both, ACV and NACV are given in the following section.

5.2 Human Factors Regarding Connected Vehicles and HMI Development

Introducing connected vehicles to the traffic changes the road-vehicle-user-system as new opportunities of interaction and exchange of information arise (Kulmala and Rämä, 2013). Potential benefits of connected vehicles such as reduced pollution, increased safety, and traffic flow can only be achieved if the technology is accepted by the users. ACV users need to feel comfortable throughout each drive and trust the system when driving manoeuvres are adapted to incoming ITS messages by the system (Elbanhawi et al., 2015). Assuming the cooperative turn with an NACV as left-turning vehicle, the ACV driver might get confused or even take over control, because the own car reduces its speed without any obvious reason. Therefore, it is important to understand whether the ACV user needs information and if so, which information these are in order to appreciate the system.

Contrary to ACV users, NACV users are still responsible to fulfil the main driving task. In the scenario of connected vehicles, drivers should react to incoming information and adapt their behaviours. In case of the cooperative turn (see Figure 2), the driver may get the information that he/she can turn first before the oncoming ACV takes its right of way. The driver, first, needs to receive and understand this message, and second, is expected to agree or just react according to the message. Otherwise, cooperation fails and expected benefits will not be achieved. One challenge for such cooperation is that implicit communication such as eye contact between drivers is not possible if one party drives automatically; alternative communication channels are needed. Moreover, NACVs have an additional need for an input channel that enables its users to tailor cooperative manoeuvres with other connected vehicles. If we modify the cooperative turn use case a bit, so that the oncoming vehicle would be a NACV and is asked to agree to the cooperation and reduce speed, the left-turning car might need an agreement to this manoeuvre in order to ensure safe driving and execute the cooperative turn.

When designing technology that enables connected, cooperative driving, we should take into account that driver's behaviour is based on mental models that represent knowledge and learning experience with the system (Wilson and Rutherford, 1989). Driver behavioural adaption will only take place if the driver trusts the system (Lee and See, 2004). Trust in the system is determined in turn by its reliability and the users' competence of the system. These factors can only be established if users are given appropriate feedback and system transparency, for instance, on system performances, processes and objectives (Rudin-Brown and Ian Noy, 2002; Lee and See, 2004; DIN EN ISO 9241-210, 2011).

Visual human-machine-interfaces (HMI) that are developed in a user-centred manner have the potential to support behavioural adaption by providing users with individually relevant information on the current traffic situation. Research focused on highway situations showed that inexperienced users of highly automated vehicles do not need much information in the longer term, but certain information should always be displayed. This includes the status of the system (autopilot vs. manual), planned driving manoeuvres and the current speed (Beggiato et al., 2015). In addition, emerging special situations, such as congestion or accidents should be displayed. Mixed, urban, connected traffic is much more complex than highway traffic. Research regarding specific information needs for mixed, urban, connected traffic is limited. Identifying such needs was part of the project and one first important step in the development process of the HMIs.

5.2.1 Identification of Information Needs

For the purpose of capturing ACV users' and NACV users' potential informational needs as a first step, three focus group discussions were conducted (N_{total} = 16); for details see (Springer et al., 2018). The focus groups consisted of experienced (N_e = 6) vs. novice (N_n = 10) participants concerning vehicle automation, which empathised with the ACV users' (N_{ACV} = 11) vs. the NACV users' (N_{NACV} = 5) perspective. On the basis of different use cases (e.g., see Section 2.2 and Figure 2) the informational needs for each group were discussed. Afterwards the relevance of each collected piece of information was rated using a point system. We developed a categorical system that distinguishes between informational needs of the different vehicle type users (NACV vs. ACV) as well as between the users' degree of experience in vehicle automation (experienced vs. non-experienced). Summing up the findings, NACV users want the HMI to support them in situation recognition as well as by giving action recommendations. In detail, information about the

Figure 7: Schematic setup for an exemplary driving test of connected and automated driving functions on a test corridor in the Digital Testbed Dresden (source: OpenStreetMap).

duration of the green and red phase, recognition of other road users and their movement direction as well as the status of cooperation were discussed as important aspects. In the cooperative turn use case feedback from the oncoming traffic relating to the cooperation were of highest value. Some information such as the duration of the green and red phase have been implemented in existing HMIs (see Figure 8), but many desired aspects have not been displayed yet.

According to the focus group results, an HMI for ACV users is supposed to increase system transparency by informing about driving manoeuvres, recognised elements and by explaining “unusual” system behaviour. For the use case cooperative turn, for example, a risk assessment of the vehicle regarding safe manoeuvring on basis of the vehicle’s capabilities and the context of the situation was rated as most important. Just as important as the risk assessment was the situation detection; information regarding the recognition of other vehicles, followed by the information of what the intention of the own vehicle is, was desired by the participants.

As an overall result, it was found that non-experienced participants need a substantially higher amount of information with a higher level of detail compared to the experienced ones. Therefore, we recommend the development of adaptive and personalisable HMIs.

5.2.2 Mock-up Evaluation

Findings of the focus groups were used for developing first new HMI mock-ups. For ACV users, the idea is to use a portable Head-Up Display (pHUD) to have a flexible tool that can be used to integrate connected driving in a conventional car. As a second step in the HMI development process, the pHUD mock-ups were discussed and evaluated within both an HMI-Workshop ($N_{HMI-WS} = 4$) with ACV experienced participants and within a usability expert evaluation ($N_{expert} = 4$) in order to identify improvement potential before realizing the HMI.

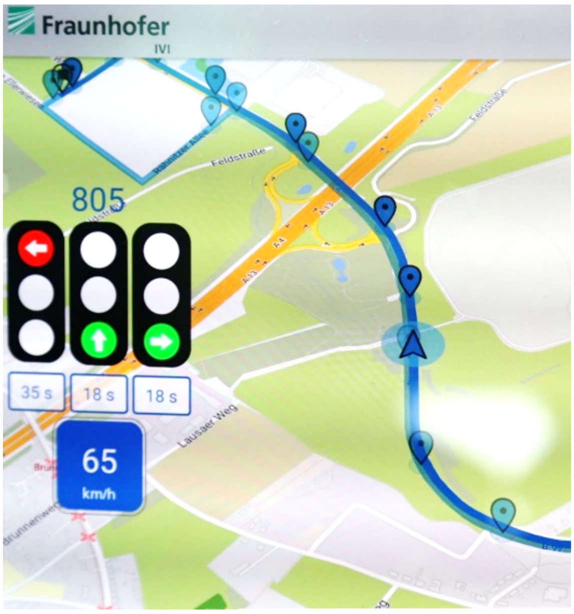

Figure 8: HMI for connected test vehicles visualising received traffic light information and speed recommendations from RSU (source: Fraunhofer IVI).

Both studies showed that the development is on a good path. However, chosen symbols for automated vehicles were not intuitive and the usage of traffic signs such as the right of way sign to describe manoeuvre recommendations was judged as confusing. For the cooperative turn, arrows showing movement intentions of the cooperating vehicles were color-coded with red, yellow and green to show the status of cooperation and who has the right of way. Participants stated that yellow-coding was seen as negligible and text would help to understand the manoeuvre recommendations. Identified potential for improvement was presented to developing partners and will be included in the further work.

6 LIVE DEMONSTRATION

The outlined architecture and the interaction of its systems and components were initially demonstrated as part of a first test event in November 2018 on the Digital Testbed Dresden. One ACV and three NACVs took part in multiple driving scenarios in public traffic on a specific test corridor. The test corridor is located in the north of the city of Dresden near the Dresden International Airport and is equipped with RSUs at four traffic light coordinated intersections

(Figure 7). The road infrastructure itself is well developed, with two lanes per direction allowing cooperative driving manoeuvres and minimizing possible interference with public road traffic. The equipped RSUs are connected to the respective traffic light control unit and to the central cloud. At the time of the driving demonstration, the RSUs supported V2X communication via 802.11p. A central element of the driving demonstration was the connected mixed traffic scenario. While driving along the test corridor, the NACVs and the ACV communicated with the RSU cloud, the central cloud as well as with each other. The test vehicles approached the equipped intersections and received the current traffic light state, the predicted remaining time as well as a speed recommendation from the connected infrastructure. In the connected vehicles, this information was forwarded to the driver via a HMI shown in Figure 8. On the left side of the HMI, the traffic light state and the remaining time was visualised for each direction whereas the speed recommendation was displayed specifically for the test vehicle's path. In addition, the test vehicles sent CAMs to the central cloud. On the return path several cooperative manoeuvres were performed, demonstrating basic functionalities for cooperation in mixed traffic scenarios (e.g. cooperative awareness) with regard to the initially described use case cooperative turn.

The driving demonstration showed that the described architectures and systems can be operated under real conditions. The event served as a starting point for an intense evaluation phase equally consisting of simulations and driving tests in public traffic.

7 CONCLUSIONS AND OUTLOOK

In this work we presented an ITS system concept for supporting cooperative driving in mixed traffic scenarios. We especially emphasised the ability of the system to incorporate vehicles equipped with heterogeneous communication technologies by introducing a heterogeneous cloud architecture that makes it possible to support connected vehicles with ITS services, e.g., recommendations regarding cooperative manoeuvres or foresight driving. We gave insights into the design and the interaction of the heterogeneous components, the automated vehicle and HMI concepts and findings for both, the ACV and NACV.

We introduced a first live demonstration, which showed that the system is usable in real mixed traffic scenarios. After the successful demonstration of the first system prototype, results of upcoming user studies focusing on the HMI as well as results of real-life tests on the test field will be integrated in the next development steps. Our goal is to end up with a user-friendly, reliable system that can cover the identified use cases and help to reach the long-term goals such as reduced traffic jams, reduced pollution, and increased traffic safety.

ACKNOWLEDGEMENTS

This work has been supported by the project HarmonizeDD funded by the Federal Ministry of Transport and Digital Infrastructure under the grant 16AVF1024.

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