BENEFITS AND TECHNOLOGY OF AN INTELLIGENT ROAD SIDE UNIT SYSTEM FOR VEHICLE TO INFRASTRUCTURE- AND INFRASTRUCTURE TO CENTRE COMMUNICATION

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ABSTRACT

Vehicle to Infrastructure (V2I) and Vehicle to Vehicle (V2V) communication will enable applications increasing traffic- safety and efficiency [2], [3], [4]. The C2C-CC [5] aims to globally harmonise related standards. The underlying architecture is widely based on the upcoming IEEE802.11p / IEEE1609 standards, which adapt WLAN technology to the automotive environment. Moreover there are specific requirements that go beyond the layers covered by radio and MAC protocols [6]. Road Side Units (RSU) are important tools to support and extend safety- as well as efficiency applications. This paper depicts beneficial applications and the technological basis for RSU systems.

APPLICATIONS AND BENEFITS OF RSU SYSTEMS FOR ROAD OPERATORS

The German research project AKTIV joins automobile manufacturers, suppliers, electronics-, telecommunication- and software companies as well as road authorities and research institutes. On the application side of things the project aims to design, develop and evaluate novel driver assistance systems, knowledge and information technologies and solutions for efficient traffic management. From technological point of view it aims at V2V and V2I communication to enable novel cooperative applications. RSUs play an important role here.
The increases in traffic volume have been constantly underestimated in the past. New studies are predicting further increases for the future. Since physical extensions of the existing road network in Central Europe can no longer be realised at a large scale, traffic control measures are increasingly deployed to extend network capacity. This is the task of the road operators. To further increase road traffic efficiency, the scope of traditional traffic control measures has to be significantly extended.

One major challenge we are facing today is to close the information loop between vehicles, roadside infrastructure and Traffic Control Centres (TCCs). This enables a wider scope of traffic control measures that prevent accidents and harmonise traffic flow on motorways as well as rural roads. The actually applied collective measures can be extended by individually generated data and by individually addressed messages (see figure 1). Therefore bidirectional Vehicle-to-Infrastructure (V2I) and Vehicle-to-Vehicle-Communication (V2V) can be deployed. Reasons for TC Hessen to participate in research projects like the German national project AKTIV [1] are as follows:

(1) Vehicle data (XFCD) can be used by TCC for traffic control measures

(2) Information from TCC can be transmitted to any vehicle in any location of the road network (no gantries needed, even when visibility is limited (fog)...)

(3) Any information can be transmitted to the driver (partial or extended functionality of traditional traffic control systems, special information depending on destination or type of vehicle, additional information)

(4) Information can be stored and processed inside the vehicle, e.g. by Advanced Driver Assistance Systems (ADAS)

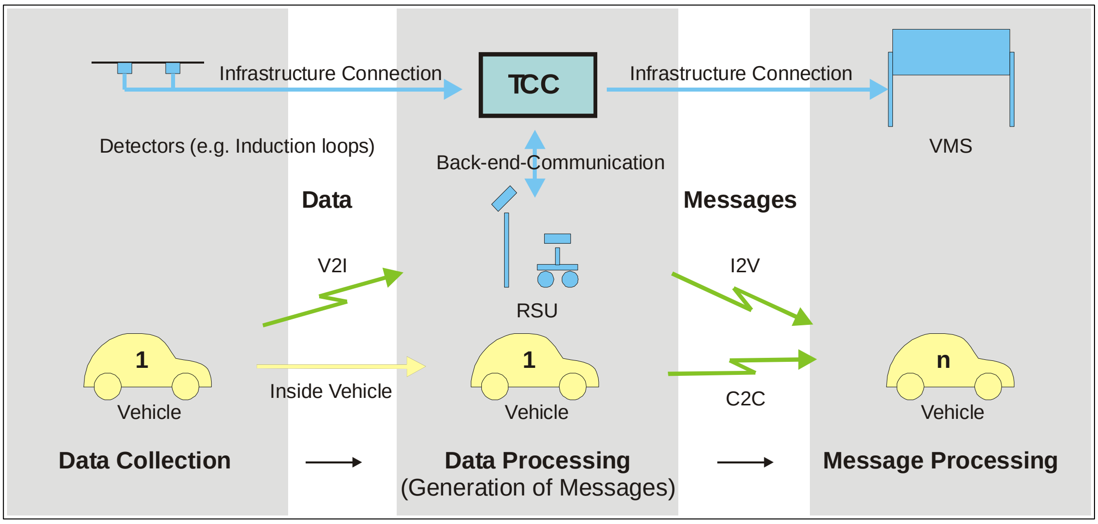

Figure 1: Coopertive traffic control

As it can be seen from the next paragraph the technological architecture of the RSU is not designed for just a single application. In fact it enables very different applications. However, in this paragraph, the focus is on one example application that enables road operators to increase traffic safety and efficiency at the same time. This application is based on the knowledge about traffic density or – even more precisely – on the knowledge about the number of vehicles on a specific lane over time.

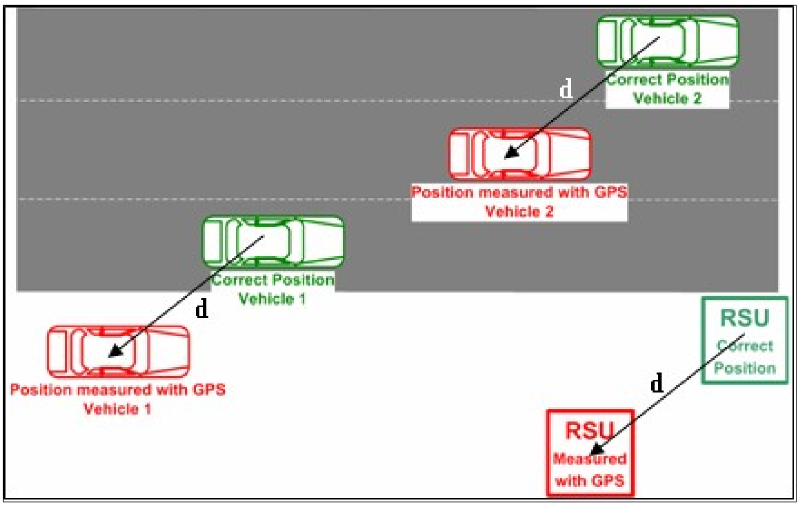

Figure 2: Correction of Vehicle position

In this context RSUs are not only interesting to send information about traffic regulations to the vehicles but also to "measure" the traffic density on single lanes.
No additional communication is required for this. In order to enable certain network layer functionalities each vehicle periodically "broadcasts" so-called network layer beacons, which also contain the current position. Because of the GPS inaccuracy the pure position cannot be used to assign the single vehicle to a certain lane. But since the RSU is placed on a fixed, well known position it is able to correct the positions received from the single vehicles. Thereby it is assumed that the GPS positions measured in the vehicles and in the RSU have the same displacement caused by the GPS error. Accordingly the RSU can calculate a displacement vector from the position measured with GPS and the stored exact position. This can be used for the correction of the positions received from the single vehicles:

$$\vec{d} = \vec{P}^{RSU}_{correct} - \vec{P}^{RSU}_{GPS}$$
$$\vec{P}^{Vehicle}_{corrected} = \vec{P}^{Vehicle}_{GPS} + \vec{d}$$

Equation 1: Correction of Vehicle's position

The scope of potential V2I- and V2V-applications covers the whole range of traditional traffic control measures. Among them count driver information (traffic state, travel times / time loss), driver warnings presented to the driver by a dedicated HMI (when approaching a congested area, car breakdown or accident location, construction site, inconvenient weather / road surface conditions) as well as advanced traffic control measures (variable speed limits, ramp metering, temporary use of hard shoulder or lane closure). Besides already existing flexibility in time (Variable Message Signs), spatial flexibility can be achieved when designing a system independently from constructional roadside equipment like gantries. Besides the presentation of information via HMI, it can be processed by ADAS.
For safety applications like warnings, a closed, protected communication network is needed. It might be required to install an RSU at every freeway junction. When entering a freeway, the needed information for the planned journey can be transmitted to the vehicle. This information can be updated at every following junction. From today`s point of view, the connection between isolated RSU and between RSU and TCC can be realised by fibre optic cables, which are available alongside German freeways increasingly (or WiMAX on rural roads). The development of mobile phone systems must be observed to identify their potential applications in this field as well.
Vehicle-to-Infrastructure (V2I) and Vehicle-to-Vehicle-Communication (V2V) can complement or replace the existing traffic control systems. A promising field of application are motorway and rural road sections without existing line or network control systems. In short- or medium-term the functionality of the new technology may be limited by legal regulations (e.g. 100 % equipment of vehicle fleet needed for mandatory regulations like speed limit). In the long run the new technology can replace the actual technology.
Research must not focus on technological aspects only but also on economic (business case) and legal aspects. A future challenge will be the transition from collectively to individually operating traffic control systems

POTENTIAL BENEFITS FOR SAFETY APPLICATIONS

According to [13] 60% of traffic accidents are caused by wrong-way-, overtaking mistakes, right of way violation, too high speed and too less distance to neighboured vehicles. Co-operative systems based on WLAN communication aim to prevent exactly those accidents. Related applications [2] share information about hazardous spots or hazardous driving situations among the vehicles in autarkic ad-hoc networks, so that affected drivers are enabled to adapt their speed and thus reduce their risk for an accident. In order to maximise reachability in sparse networks store and forward mechanisms are applied. But still messages might not reach affected vehicles or might even get completely lost. Another aspect is that there is safety related information, e.g. about construction sites, which cannot be sensed by the vehicles themselves. Therefore this information has to be provided to the ad-hoc network from outside.

In this context RSU systems can keep safety related information alive in the zone of relevance and thus effectively increase the reachability of ad-hoc networks. Moreover it can feed the vehicular ad-hoc network with safety related information about static road hazards or risks (road works, curvy road ahead, low bridge ahead etc.). Beyond this intelligent de-central algorithms running on the RSU can fuse different information (e.g. from whether sensors, information about traffic density and traffic flow etc.) in order to derive appropriate traffic regulation measures that reduce the risk for accidents. Moreover this fused information can provided to traffic management centres. This offers a finer resolved view on the current traffic situation and enables operators to perform dedicated localised safety measures.

Following, RSU systems will be a vital element of future cooperative safety applications. This aspect will be even more important for the market introduction phase, where only a small number of vehicles are equipped. In the following paragraphs an architecture for an RSU system is proposed, which equally supports traffic efficiency- and safety applications.

ARCHITECTURAL RSU CONCEPT

As it can be seen from the previous paragraphs, there are a huge number of application scenarios with completely different requirements towards the technological platform. Naturally it makes no sense to have a different system for each application. Therefore the goal of this concept is to specify a platform, which provides the transport capabilities of the single communication media to the application in a defined abstract way. For this the applications have to be completely decoupled from the lower layers of the protocol stack. Only with this approach it can be ensured that different applications can use differently configured RSU platforms in various scenarios. Moreover it is ensured that one RSU can simultaneously serve several different applications. Following the same system can be used for any application in motorway-, construction site-, rural-road- and city scenarios. At least the possibilities of potential applications are only limited by the current transport capabilities of the single communication media. Summarised it can be said that the described concept will define an system open for any kind of application, which is based on V2I communication and the communication to management- or service centres.

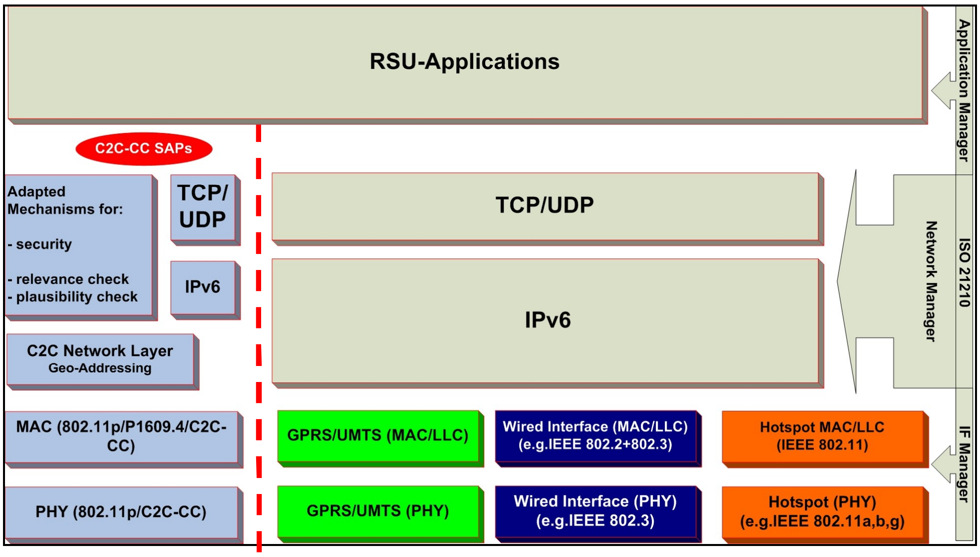

Figure 3: RSU Protocol Architecture

As it is indicated by the dashed red line in the graphic above the drafted protocol stack of the RSU system is split in two parts. The left part (light blue) is describing the communication to the vehicles (V2I), which is in the following referred to as "front-end communication". The right part of the protocol stack defines the communication to the centre side, which is in the following referred to as "back-end communication". This strict differentiation is absolutely necessary because it is about completely different communication scenarios and related requirements. Whereas the back-end scenario is mostly a point to point communication with more or less reliable and deterministic parameters (e.g. available bandwidth, connection stability etc.), the front-end scenario can be either point to point or point to multi-point communication where the constraints depend from various variable conditions (e.g. velocity of the vehicles, number of the vehicles in the communication range etc.).
Front-end communication is exclusively based on WLAN according to the Protocol Stack that is proposed by the Car to Car Communication Consortium. Although Safespot [12] mainly focuses on V2V applications the proposed RSU architecture is compliant because for front-end communication the same protocol stack is used. The back-end communication instead can make use of different communication media. Moreover RSUs in different scenarios can be differently configured for back-end communication. This requires a proper framework that provides a harmonised base for applications on differently configured RSUs. Moreover it has to flexibly steer the communication between RSU- and centre based applications via the available media. For this the proposed architecture applies a standard from the CALM family (ISO21210). The architecture for the back-end communication is therefore compliant to the discussed mechanisms in CVIS [4]. In the following front-end and back-end communication shall be explained more in detail.

FRONT-END COMMUNICATION

For the front-end communication there is only one medium available in the RSU. Accordingly applications use defined SAPs to **immediately** access the lower protocol layers. The architecture is based on the protocol stack as it is currently described by the Car to Car Communication Consortium (graphic: light blue blocks). PHY- and MAC layer are widely based on the upcoming standards IEEE 802.11p and IEEE 1609.4. Above the MAC Layer it is distinguished between safety and service-/efficiency- oriented applications.

The C2C- Network Layer is based on GeoAdressing and GeoCast-Forwarding and especially used by safety related applications. There are a lot of requirements that must be fulfilled in order to ensure that messages are reliably delivered to the addressed nodes in scattered networks while at the same time it must be ensured that the network does not get congested in high density scenarios. There are already a lot of valuable mechanisms to ensure this [7],[8],[9],[10],[11]. All these mechanisms and standard ad-hoc routing algorithms are discussed against the particular requirements of the automotive environment in [6]. In addition to the adapted network layer other mechanisms are necessary that check spatial relevance and validate the plausibility of received messages. At this point it has to be said that most of those protocols are targeting on de-central communication scenarios. In this context one could consider the RSU to be a parking vehicle. But nevertheless one should not forget that about the knowledge that it will never move. Moreover it will serve particular applications with dedicated requirements for the dissemination of information. Therefore RSUs might have particular network layer mechanisms. Nevertheless the de-central protocols have to be supported of course. Only in this way it can be ensured that V2I and V2V communication stays compatible. It must be ensured that the information of an RSU also propagates outside of its communication range in the de-central vehicular ad-hoc network.
Service- or efficiency oriented applications are mostly assigned to TCP/IP or UDP/IP. However, there are some efficiency applications that require GeoAdressing. Therefore the corresponding mechanisms of the C2C-Network Layer can also be accessed by these applications. In this context the challenge for the platform is to harmonise network and transport protocols in order to enable the co-existence of safety and non-safety oriented applications.

BACK-END COMMUNICATION

For the back-end communication basically existing and well known technology shall be used. Currently two options for the communication are considered. As far as the infrastructure is available a RSU might use wired media (e.g. Fast Ethernet via fibre optics) in order to communicate with a management centre. For the case that wired communication is not possible the RSU platform supports a wireless link which is based on cellular technology. But there are various other technologies (e.g. WiMAX) considerable, which could also be applied for back-end communication. Accordingly different configurations of an RSU with different communication media can be foreseen. Moreover the choice for a specific communication medium might depend from the current communication parameters of all available media.
If one would define an architecture with a dedicated single SAP for each medium the applications would have to be able to deal with different hardware configurations in different RSUs. In the end for each possible hardware configuration a different implementation would be required. Moreover the application itself would have to continuously compare the actual state of each communication medium in order to decide which one to use. This brings a huge amount of additional implementation work. Following this approach is less appropriate. Therefore the lower layers have to be decoupled, which enables that the same implementation applies in all considerable RSU configurations. Moreover the choice of a communication medium has to be departed from the application. For this an additional functionality is required in the RSU, which selects the best suited communication medium based on some criteria previously defined by the application. This is exactly what is provided in an upcoming standard of the CALM family: ISO21210.

It can be summarised that the drafted protocol stack defines a CALM conform architecture for the back-end communication and a more or less stand-alone stack for the front-end communication. This makes sense before the background that there is only one communication medium the for front-end and that a direct access of the applications to the lower layers safe valuable time in the front-end communication scenario. This also reflects the discussions currently ongoing in related European projects like e.g. [4].

FUNCTIONAL SYSTEM DESIGN AND DEMONSTRATOR SETUP

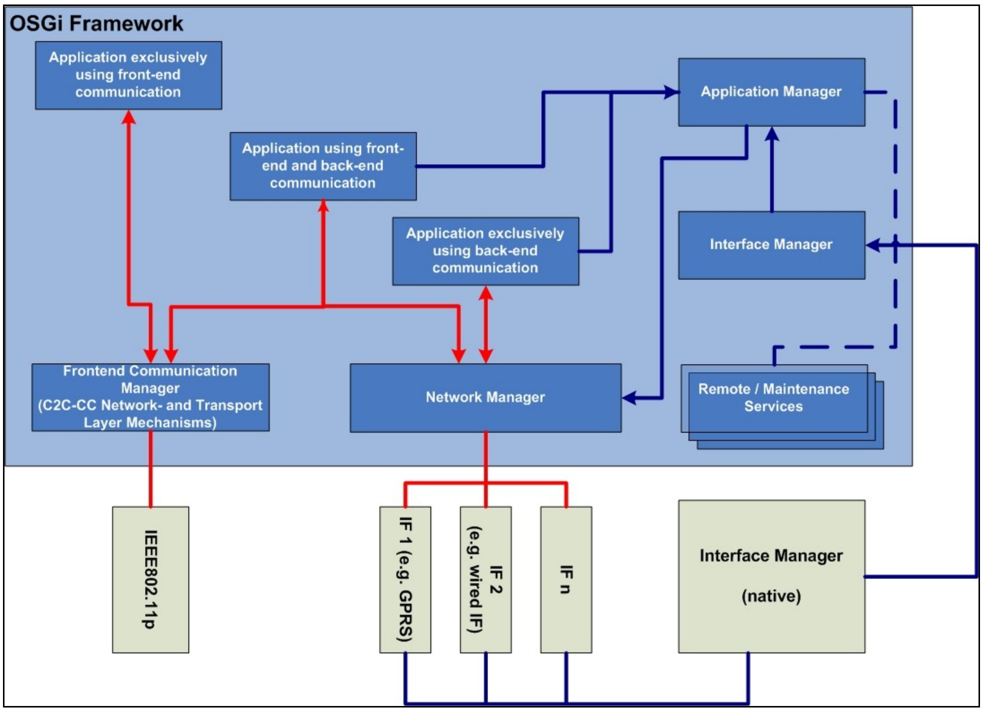

Figure 4: Possible Setup of demonstration system

It can be seen from the graphic above that there are basically three types of applications: applications exclusively using front-end communication, applications exclusively based on back-end communication and applications using both options. For front-end communication the applications are immediately interacting with the lower layers of the C2C-Protocol Stack via the so-called Front-End Communication Manager.
For the backend communication instead, there are three entities (Application-, Network-, Interface Manager) decoupling the applications from the lower protocol layers according to ISO 21210. The central component is the Application manager. It obtains the current status of all communication media from the interface manager. Based on this the application manager selects the best suited medium for each application. The decision is based on a so-called policy, which has to be previously defined by each application. It lists relevant criteria (e.g. available bandwidth, operational costs etc.) for the selection of the communication medium. In this way the same implementation of a specific application can be used on differently configured RSU systems. Moreover the currently best suited medium is selected without any additional effort in the implementation. As soon as the configuration of an RSU changes only the policies of the installed applications have to be adapted. There are no changes necessary in the implementation of the applications. In this way Application Manager and the Application Policy decouple the application from the lower layers. As soon as the communication medium

for an application has been selected by the Application Manager, the Network Manager is in charge to route the data packets from the application to the medium and the way back.
As base for an RSU demonstrator an OSGi [14] framework shall be applied. There are two reasons for that. First is to ensure compliancy with other European projects like CVIS and GST. Second is that OSGi already provides useful tools for remote management of the system. It offers e.g. to start, stop, install or de-install applications and provides version management. In order to provide secure communication with back-end applications and secure remote administration the RSU will periodically exchange the key infrastructure with the centre based Remote Administration Unit.

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