REQUIREMENTS ON VEHICLE POSITIONING AND MAP REFERENCING FOR CO-OPERATIVE SYSTEMS - COOPERS

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ABSTRACT

Applications in the area of Intelligent Communication Technologies (ICT) for Intelligent Transport Systems (ITS) are one of the key means of enhancing efficient and safe driving on the road infrastructure. The new developments are focusing on Co-operative Traffic Management Systems with the establishment of a wireless infrastructure-to-vehicle data communication link for the transmission of safety critical as well as legal binding messages from the road operator into the vehicle.

The Integrated Project COOPERS that is co-funded by the European Commission is also focusing on the continuous bidirectional infrastructure-to-vehicle communication to provide the driver in time with the relevant safety critical information. Hereby requirements on the positioning parameters and the map matching process are defined.

This paper will discuss these requirements including solutions that are followed within the COOPERS project. The key element in the COOPERS approach is with the Robust Positioning Unit. This concept will be described in this paper as well as the limiting factors of currently existing navigable map-products.

KEYWORDS

COOPERS, co-operative systems, map requirements, robust positioning, infrastructure-to-vehicle communication, Co-operative Traffic Management, on-board-unit, OBU, RPU, I2V

INTRODUCTION

In the last years the tasks of road network operators increased from tendering the construction, operation and maintenance of the road network to operation with a strong link to traffic management and traffic information to the drivers. It was mainly static information like road signs along the roadside that informed the driver about possible dangerous road sections (e.g. speed reduction with rain and/or snow). But traffic increased rapidly and the road operators had to manage new challenges because of very high traffic volumes on the road network and resulting frequent traffic jams. So traffic management with dynamic information became an additional task for motorway operators complement to their traditional functions.

To manage, coordinate and influence dense traffic situations Variable Message Signs (VMS) have been developed in the 1980ies in dense traffic-areas that are mainly close to and/or within agglomerations. This signs added flexibility in the finality of information to the drivers and make it possible to adapt signs to changing traffic conditions (e.g. speed limit in relation to the current traffic flow on a single section). Traffic models were developed to influence the traffic in a way to get as many cars as possible through a specific section of infrastructure. But also VMS have a big disadvantage: beside the high cost of over-head signs (and these are necessary for legal reasons) the information has still semi-static character in the meaning of informing the driver only at a specific point on the traffic conditions of the following road section. This means that the driver is informed only at the point of the VMS, and that can be in many cases to late for a route-decision by the driver. Additionally the driver must recognise and understand the information of the VMS. If the VMS shows only speed limits the meaning should be clear to the driver. But if there is also a text-message shown, the driver has to understand the meaning and this might be difficult especially for tourists and foreign travellers.

The language problem was solved by the introduction of the RDS-TMC (Traffic Message Channel via Radio Data System) Service at the beginning of this millennium. Here a Broadcast Company sends out digitalised road information via the RDS-channel. This information can be interpreted by an On-Board-Unit (OBU) and communicated to the driver. This communication to the driver can happen by showing the current situation through a Navigation System (e.g. rerouting caused by traffic jams) or by presenting the information directly to the driver via audio-visual information (e.g. wrong way driver warning). Beside the language independency also the problem of driver information available only in populous areas was solved because TMC messages can be generated for all sections along motorways and main roads. But RDS-TMC information has its limits. On one hand only a specific set of information can be transmitted to the driver, and most traffic information is appointed to a road-section, but no point-location, and some road sections are as long as the distance between two motorway-exits. Both restrictions (limitations in the message set and in the number of road sections) are caused by the limited bandwidth that can be used for the RDS messages.

CO-OPERATIVE TRAFFIC MANAGEMENT

Current Research Projects over the world (e.g. COOPERS – Co-operative Systems for Intelligent Road Safety) focus on the next level of traffic management and driver information: Co-operative Traffic Management (1). With such systems it will be possible to compute and transmit safety relevant information about the current traffic and road-surface status directly from the road operator to the drivers by using direct infrastructure to vehicle (I2V) communication technologies. An additional advantage of this co-operative approach is the possibility of the setup of a bidirectional communication link that also enables vehicle to infrastructure (V2I) communication. Via such a link road safety relevant information that was generated by in-vehicle sensors in the car can be submitted to the Traffic Control Centre (TCC). These in-vehicle generated data can be used to get an accurate overview of the whole traffic and road surface situation on the road network. Vice versa these data will be used to generate specific information for the vehicles on a road segment.

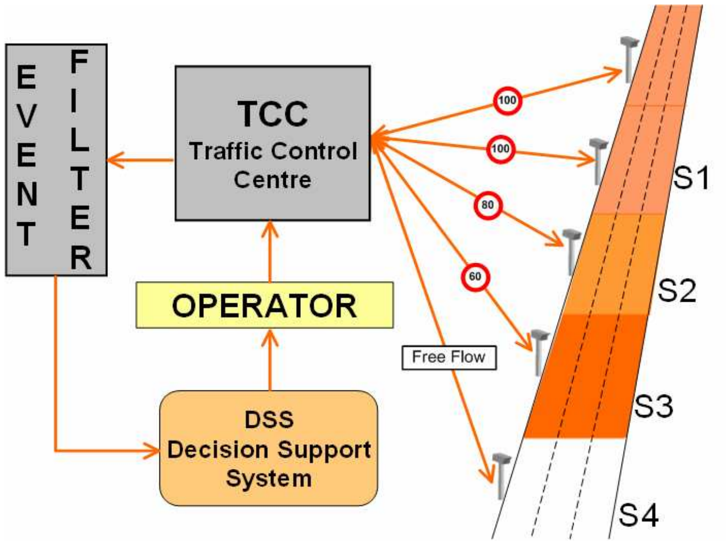

Figure 1: Information loop for Co-operative Traffic Management

Figure 1 shows the information cycle of such a system: traffic and environmental data are acquired both roadside and in-vehicle and transmitted to the TCC – a concept that is also followed by the Vehicle-Infrastructure Integration (VII) (2). The data are centrally processed to detect events that influence traffic. If an event has been detected, the Decision Support System (DSS) calculates possible actions to alert involved drivers about upcoming events as well as to improve the traffic performance and support the operator's decision task. The necessary transmission of data is then performed in a sequential process to the vehicles within the relevant road segments only.

Within the European Integrated Project COOPERS the whole process chain of Co-operative Traffic Management will be demonstrated and evaluated. Hereby one special focus will be the evaluation of the communication technologies that are usable for bidirectional I2V communication (see figure 2): cell based technologies (e.g. GSM/GPRS, WiMAX), broadcast media (e.g. DAB, DVB-H) and Dedicated Short range Communication (DSRC) technologies (e.g. Infrared, CALM-M5).

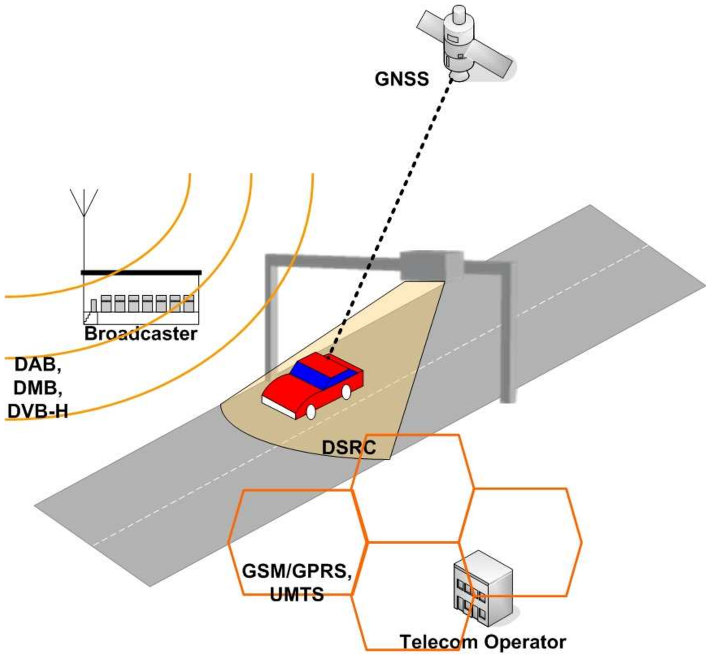

Figure 2: Communication technologies usable for bidirectional I2V data communication

Via these communication media safety relevant information and driving recommendations will be transmitted to the drivers in a specific road segment. Hereby it is important to reach all drivers with a minimum delay time (the throughput time from the detection of an event to the information of the following drivers should be below one minute) and with a geographical precise indication (point reference instead of road-section reference). Hereby following safety-critical services (out of 12 services in total) are identified within COOPERS (3):

- Accident/incident warning
- Road/weather condition warning
- Roadwork information
- Lane utilization information
- In-vehicle variable speed limit information
- Traffic congestion warning
- Intelligent speed adaptation (ISA) with infrastructure link

Beside the transmission of the information about upcoming events and a recommendation to the driver also the location information must be transmitted to the single On Board Unit (OBU) within the vehicle where the geo-referencing will take place. Hereby currently three location referencing methods are existing (4):

- TMC location referencing (e.g. TPEG-Loc)
- On the Fly method (e.g. AGORA-C) without a precise known geo-resolution (5)
- A simple accessible WGS84 co-ordinate together with a road description and a heading

For most of the identified services, where a point location with an accuracy of approximately 30 meters is sufficient, these geo-referencing methodologies are well working. But some services – In-vehicle variable speed limit information, ISA with infrastructure link, and lane utilization information – need a higher accuracy. Here the geo referencing of the exact lane is required.

Lane Utilization Information

The services for lane utilization information are divided within COOPERS into three different sub-services: keep in lane (no take over allowed), change lane (if an accident or construction closes a lane), and use additional lane (hard shoulder, if opened for free flow by the road operator).

In-Vehicle Variable Speed Limit Information and ISA with Infrastructure Link

Within COOPERS these services are informing the driver about the current legal speed limitation on the section he is currently driving on. If this information is basis for an Intelligent Speed Adaptation (ISA) system within the vehicle, highest accuracy must be ensured. In some locations it is also possible, that different lanes have different maximum speed limitations. In these locations a lane dependent geo-referencing must be ensured to have the valid speed correctly displayed.

But also for the other services a lane referencing of the information is useful because this enables an intelligent On-Board-Unit (OBU) to transmit a specific and very exact recommendation to the driver without leaving space for interpretation. This will also reduce the information overload to the driver by giving lane dependent instructions.

Extended Floating Car Data (xFCD)

As described in the scenario for Co-operative Traffic Management via the bidirectional communication link also data need to be transferred from the vehicle to the infrastructure operator (see also figure 1). In this approach in-vehicle generated sensor data are transmitted anonymously from the vehicle to the infrastructure operator as extended Floating Car Data (xFCD) via a cell based or dedicated short range communication media to detect events and possible dangerous situations (e.g. slippery road) close to real time.

Hereby the in-vehicle generated data are read out of the in-vehicle data-bus (CAN-bus) and will include vehicle kinematics information (e.g. wheel speeds), safety systems activity information (e.g. ABS, ESP, emergency flasher), weather information (e.g. outside air temperature, rain sensor status, fog lamp status), and vehicle GNSS position. Also here a lane-precise resolution of the position would be beneficial, but at least – along motorways – a driving-direction dependent resolution for event detection is necessary.

VEHICLE POSITIONING

As discussed above, a lane precise geo-referencing of the vehicle is absolutely necessary to provide the driver with a precise, timely and specific recommendation or instruction for the current driving situation. For this geo-referencing requirement the longitudinal accuracy in driving direction (+/- 30 meters) has minor resolution needs as the transversal accuracy (+/- 1 meter), as it can also be seen in figure 3.

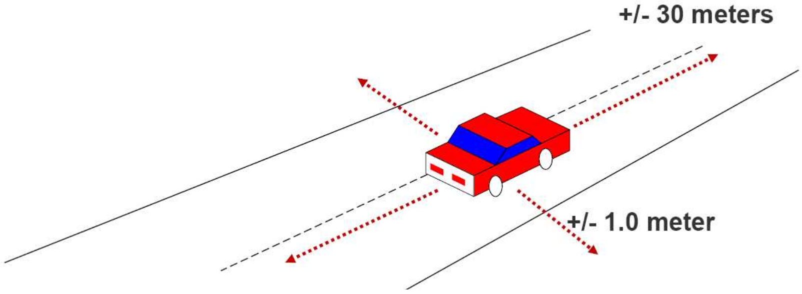

Figure 3: Requirements for the longitudinal and transversal positioning accuracy

For the lane specific geo-referencing currently introduced methodologies like the map-matching process that is standard in existing navigational systems are not useable, because in this process the GPS-position is switched to the logical position on the digital map of the Navigational System. These are additional requirements to the positioning process because the existing information within the navigable map databases can not support this requirement. Therefore an integrated system solution that combines different and complementary sensors is needed to catch the lane specific positioning. Many solutions are currently under discussion, e.g. adding infrastructure based sensors or to use cellular networks for a better positioning (6). Within the COOPERS approach the in-vehicle equipment is responsible for the positioning process. This starts with the mounting of the GNSS antenna and the transformation of the exact antenna position on the vehicle's roof with an accuracy of less than 10 cm into the Robust Positioning System. (7)

Robust Positioning Unit

This Robust Positioning System (RPU) is the key element for a high accuracy, a high reliability and integrity (8). Within the RPU a fusion of different sensors will be established:

- GNSS receiver
- Wheel speed
- Turn-rate-sensor (Gyro)
- Differential-Odometer
- Integration of available in car sensors from the CAN-Bus

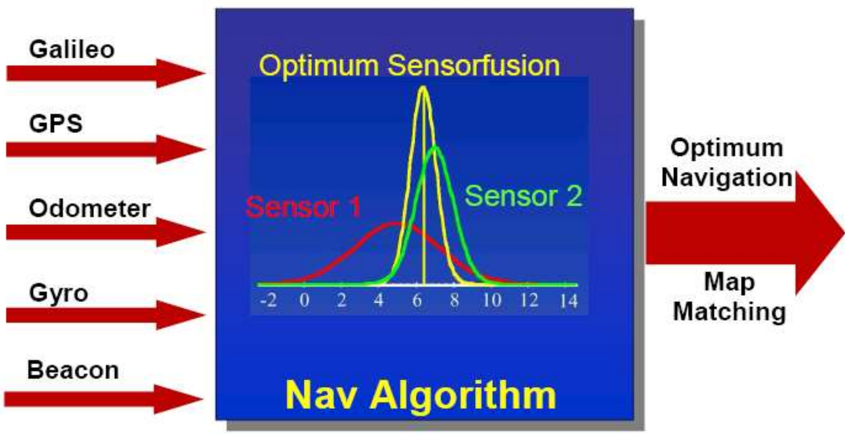

Figure 4: COOPERS concept of sensor data fusion within the Robust Positioning Unit (RPU)

This sensor data fusion, as it is shown in figure 4, will lead to an "optimum navigation map matching" in the meaning that the very precise measured geo-position will be basis for continuous driver information. So the driver does not only rely on the GNSS data – that are e.g. not available in tunnels or dense city areas – but a continuous precise position needs to be guaranteed.

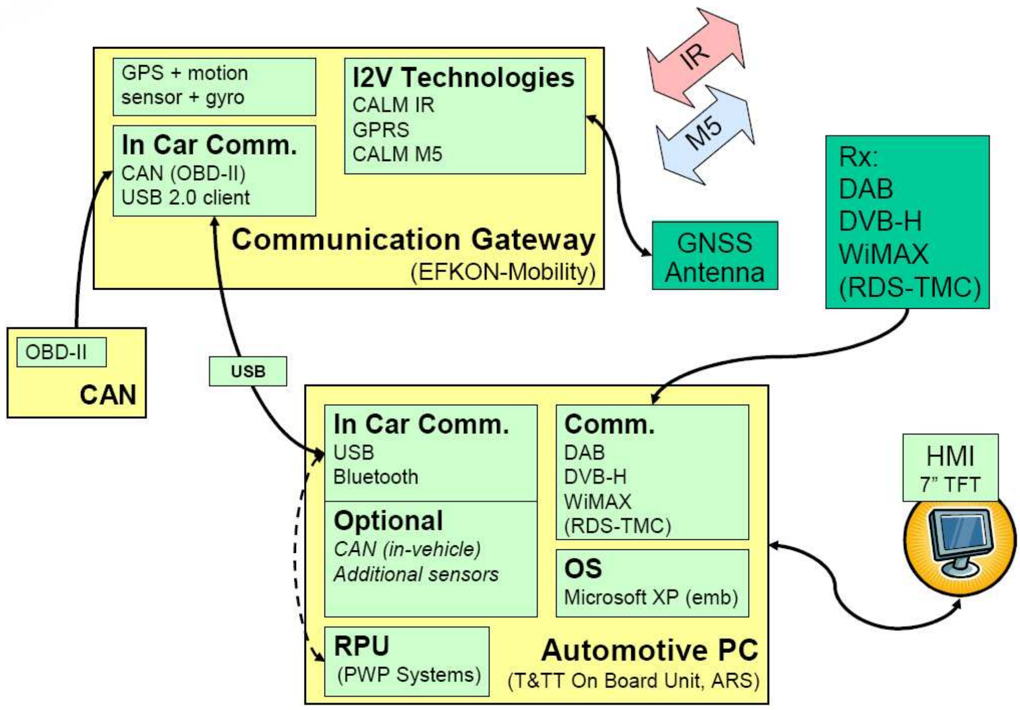

Figure 5: Architecture of the COOPERS-OBU including the Robust Positioning Unit

The exact position elaborated by the RPU needs to migrated towards a real time system to the vehicles On-Board-Unit (OBU) where the vehicle position needs to be matched with the on-board map database as well as with the other OBU elements (e.g. communication gateway) as it can be seen in figure 5.

MAP REFERENCING

Current Navigation Systems will now match the elaborated exact position of the vehicle to the on-board map database. This process will produce a referencing error with up to 100 meters. So the OBU will switch the vehicle on the GIS-database to a wrong position without informing the driver about the reliability of the current information displayed on the navigation device. If this positioning error is longitudinal in driving direction the impact might be smaller than a transversal error (see also figure 3).

But that the COOPERS concept with lane specific advices to the driver works, the fusion of the precise positioning data generated by the RPU into the on-board map database must be enabled. In this context two limiting factors are existing:

- The accuracy of the map
- The content of the map

Accuracy of on-board map databases

Every map is only a generalised picture of the reality. In current navigable map-databases that are used in Navigation Systems the whole navigable geometry is represented a centreline of the road. Herby the shape of the road is followed by nodes and shape-points that are connected by links. One problem in this approach is the definition of the centreline (e.g. at huge junctions, at places, is the hardshoulder part of the road?). Here a clear and unique definition that is approved by the navigable map producers would be required.

But even if then the current used coordinate system reduces the accuracy of the navigable map databases. The whole points (nodes and shape-points) of navigable maps are referenced to the WGS84 coordinate system, where the accuracy of the coordinates has currently 10 micro-degrees. This relates in Central Europe to an accuracy of approximately 1.1 meters transversal and 0.7 meters longitudinal (7). As it can be seen, here the transversal error is higher that the requirement of 1 meter necessary for lane specific positioning.

Content of on-board map databases

The second limiting factor for lane specific positioning is the content of on-board map databases. Current maps are optimised for navigational issues without lane specific advices. But with the introduction of ADAS (Advanced Driving Assistant Systems) services (9) in the last years also the content of the maps became enlarged for the main road network and for large urban junctions. Hereby the number of lanes is stored as attribute to the single links of the map database for motorways and the main road network.

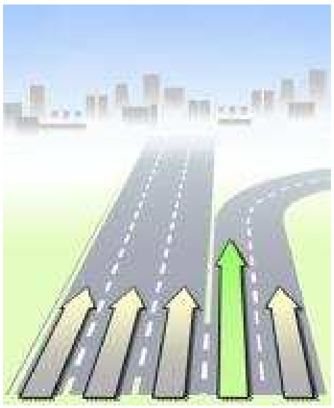

Figure 6: map representation of the “extended number of lanes” concept

In the last years also maps with the “extended number of lanes” are available that indicate the exact number of lanes with the additional indication of exit lanes along motorways and turn lanes at huge junctions. Additional restrictions for lanes are indicating special users (e.g. bus lanes, HOV lanes) or time restrictions (e.g. closed for all except buses from 8am to 10am). These attributes help to improve the map content.

Additional efforts need to be taken to improve the quality of the navigable map-database:

- Unique definition of the centreline of the road
- Enhanced accuracy of the coordinate system
- Upgraded road-model with a more reliable geometry

These enhancements of existing map models to support a lane specific positioning are very complex and it is unrealistic that the whole map model will be changed, which would need a complete new collection of all geometry including all attributes. Therefore it is necessary to develop methods to increase the map referencing process.

CALIBRATION OF THE ON-BOARD-UNIT AT GANTRIES

One possibility is the transversal calibration (normal to the driving direction) of the positioning and map-referencing-process at gantries (figure 7). In this approach lane specific information about the current real position will be sent via infra-red communication from the road operator to the vehicle. With this lane-positioning-information the on-board-equipment gets the possibility to calibrate itself. Of course, this communication link can also be used for the transmission of safety related information.

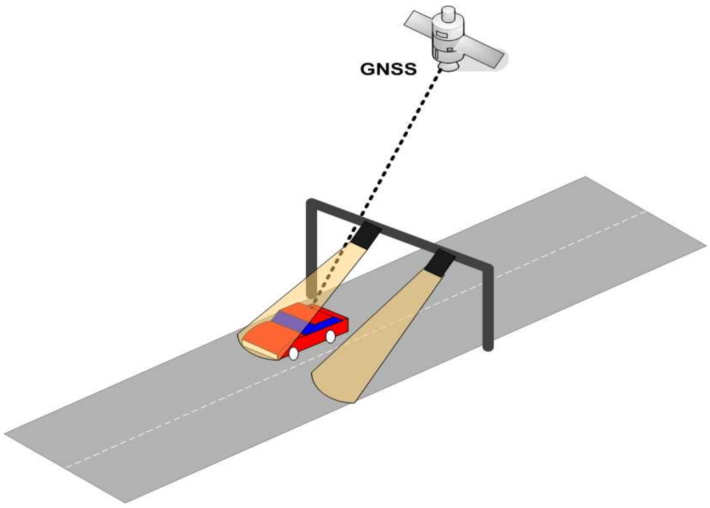

Figure 7: lane specific positioning by calibration of the OBU at gantries by using infra-red-communication.

CONCLUSION

Recent R&D projects in the area of traffic management (e.g. COOPERS) are researching in the area of co-operative systems. Beside the technical feasibility of the data communication and the timely transmission of the safety relevant information to the drivers one big problem is with the exact geo-positioning of the vehicle, the matching of the event to the in-car map-database and the proper presentation to the driver. By analysing co-operative services that are feasible to enhance safety one recommendation is with a lane-specific positioning.

By analysing the current positioning procedure of vehicles in current navigation systems two areas for improvement can be defined: the positioning of the vehicle and the map referencing.

The positioning of the vehicle can be improved by using a Robust Positioning Unit that is developed within the COOPERS project. Hereby a fusion of several in-vehicle sensors will lead to a optimum map matching process. It is expected, that with this process a continuous precise position of the vehicle can be guaranteed.

For the map referencing process the requirements of the navigable on-board map database are very difficult to achieve. This results from the accuracy-error of the coordinate reference system (WGS84), the content of the map database where the number of lanes is only added as additional attribute to the centreline representation of the road geometry, and the map model itself with no unique definition of the road centreline which leads to misinterpretations.

One possibility for enhancing the current map matching process might be the calibration of the On-Board-Equipment at gantries along the road network that transmit information about the lane specific position into the vehicle.

Within the European Integrated Project COOPERS a demonstration of a more reliable and robust positioning including an enhanced map-matching process will be established.

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