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V2X COOPERATIVE SYSTEMS –
ON THE WAY TO NEXT GENERATION ITS

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Abstract: After several years of extensive research and standardization both in Europe and North America, cooperative systems based on vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication (V2X) are entering the phase of initial deployments. The basic technology feasibility of IEEE 802.11p wireless communication has been proven and several Field Operational Tests (FOT) across the globe are preparing the actual deployment. In order to benefit by the significant improvements enabled by the V2X use cases in terms of traffic safety and efficiency, the system has to operate reliably under high traffic loads providing a robust security scheme and a viable business case for all stakeholders. In addition, the cooperative nature of V2X requires new ways of data management in the traffic management centers (TMCs). TMCs will have to process large amounts of dynamic real time data, to aggregate these data with fixed sensor data and transmit location based traffic information dynamically to the traffic participants. The paper gives an up-to date overview of current projects, standardization, and system architecture of V2X cooperative systems.
Keywords: V2X communications, ITS, cooperative systems, V2V, V2I, WAVE, ITS-G5

1. INTRODUCTION

Vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication (together referred as V2X) is one core technology in the "connected vehicle" environment. Road operators, infrastructure, vehicles, their drivers, and other road users must cooperate to deliver the most efficient, safe, secure, and comfortable journey. V2X will be a major contributor to this concept of cooperative mobility.

There are many different terms of systems in this area, e.g. Intelligent Transport Systems (ITS), Car-to-Car (C2C) and Car-to-Infrastructure (C2I) combined in C2X communication systems, cooperative systems. In this paper mainly the term V2X cooperative systems is used, except at direct references to projects or standards, where other terms are common.

V2X in context of this paper is based on 5.9 GHz radio communication (although complementary technologies are mentioned in Chapter 3.2), a bidirectional, short-range wireless communications technology designed especially for fast moving objects like

vehicles. In general it allows vehicles to exchange data with each other and infrastructure, sensors and actors similar to Wi-Fi communication, but using efficient ad-hoc features. In context of 5.9 GHz communications the stationary ITS station (beside or above the road) is called Roadside Unit (RSU) and the mobile ITS station (in the vehicle) is called Onboard Unit (OBU).

It all depends on the number of vehicles equipped with 5.9 GHz technology. With V2X every vehicle is able to sense its surroundings. It can use information about vehicles in its vicinity to calculate its current and future position thereby creating situational awareness. This enables a number of safety services for avoiding crashes or predicting dangerous situations.

V2I in particular can improve traffic efficiency and support e.g. eco-friendly driving, change to public transportations, and route optimization for fleets. Depending on the traffic load, V2X RSUs connected to the Traffic Management Center (TMC) can issue advisories to drivers recommending alternate routes or offering parking facilities near public transportation stations supporting multi-modal transportation. V2X equipped traffic lights can inform drivers about the time until the next traffic signal change or indicate the optimum speed to pass the intersection with green light or prevent signal violation increasing drivers attention.

The reminder of this paper is structured as follows. In Chapter 2 an overview about current projects and institutions in the area of V2X cooperative systems is given. Chapter 3 explains the components of such a system starting with a system overview in Chapter 3.1. V2X communication technologies and their related standardization is explained in Chapter 3.2. In Chapter 3.3 the System Architecture of the TMC is described. The last chapter of this paper, Chapter 3.4 gives an overview about applications and use cases of V2X cooperative systems.

2. OVERVIEW OF EUROPEAN V2X COOPERATIVE SYSTEMS PROJECTS / INSTITUTIONS

Currently many projects are dealing with the topic V2X cooperative systems. The type of the projects is ranging from research projects over development projects to field operational tests (FOTs). In the following important projects in Europe are listed (this list is not exhaustive). The importance of the projects can be seen that many of them are co-funded by the European Commission (EC) under the 7th RTD Framework Programme for Information and Communication Technologies (FP7-ICT) like DRIVE C2X, COMeSafety2, FOTsis, FOTNET2, eCoMove, ECOSTAND, and PRESERVE. Further projects co-funded by the EC are e.g. COSMO. National funded projects in the field of V2X cooperative systems are simTD in Germany and Testfeld Telematik in Austria.

The goal of DRIVE C2X, 01/2011-12/2013, Ref. 2 is to carry out comprehensive assessment of cooperative systems through FOTs. It is built up on the predecessor PRE-DRIVE C2X Ref. 3 and is deploying test sites in seven European countries. Beside harmonizing Europe-wide testing the awareness in the general public shall raise and

feedback for standardization organizations shall be provided. COMeSafety2, 01/2011-12/2013, Ref. 4 has as objectives the support of the European Community wide implementation of V2X cooperative systems, especially for safety applications, by supporting the European standardization. The international cooperation of Europe shall be assisted and the benefits of world-wide FOTs outcomes shall be maximized. Further the project shall give the necessary experience to prepare the deployment of V2X systems in Europe and elsewhere on the globe. Also for FOTsis, 04/2011-09/2014, Ref. 5 and FOTNET2, 01/2011-12/2013, Ref. 6 the basis is, as the name already refers, on FOTs, where FOTsis focuses on seven close-to-market cooperative (I2V, V2I, and infrastructure-to-infrastructure (I2I)) technologies. Their effectiveness and their potential for full-scale deployment on European roads shall be assessed in detail. The main goal of FOTNET2 is to increase the development of the strategic networking of current and future national, European and Global FOTs. In eCoMove, 04/2010-03/2013, Ref. 7 and ECOSTAND, 12/2012-11/2013, Ref. 8 the ecological aspect of V2X cooperative systems is the main priority. eCoMove aims to decrease the fuel consumption by assisting drivers with routing advices and enhance their green driving, optimization of the tour planning for fleet managers and assisting the road operators to balance the traffic flow. ECOSTAND's aim is to reduce the environmental impact of transport by providing a platform for cooperation between the main three "ITS-regions" Europe, Japan, and USA. The focus of the project PRESERVE, 01/2011-12/2014, Ref. 9 are security and privacy issues. PRESERVE has the goal to design and implement a scalable, secure V2X communication system and test it in FOTs.

The EC project COSMO, 11/2010-12/2013, Ref. 10 also focuses on energy efficiency of V2X cooperative systems. The project investigates the impact of such systems on the environment, considering fuel consumption and CO_2 emissions, based on quantified results and detailed specifications (technical, legal, and organizational) shall be developed.

The German national co-funded project simTD, 09/2008-2013, Ref. 11 focuses on the technical implementation and testing of a hybrid communication system. One of the goals is an integrated connection, a seamless integration of vehicles, communication and traffic technologies into one overall system. The implementation of several applications on an integrated platform shall be explored in a FOT with a large number of vehicles (hundreds) in a field test area near Frankfurt/Main, Germany. In the Austrian national co-funded project Testfeld Telematik, 03/2011-08/2013, Ref. 12 a complete V2X system is deployed, with a set of use cases including in-vehicle signage, information about public transportations interval, park&ride possibilities and, flight delays. The system is ready for test and evaluation in a FOT by 100 test users (two times 50) driving in the test area in the vicinity of Vienna in their daily life.

Two major interest groups are driving the development and deployment of the V2X technology and system. The CAR 2 CAR Communication Consortium (C2C-CC) Ref. 13 led by European vehicle manufacturers and supported by equipment suppliers, research organizations and other partners. The C2C-CC is working to speed-up the market penetration by realistic deployment strategies and business models and a roadmap for deployment of V2X cooperative systems. The consortium is validating the technical and commercial feasibility of such systems by demonstrations and FOTs. Beside the focus of the C2C-CC on V2V communications the cooperation platform Amsterdam Group Ref. 14 concentrates more on the integration of road authorities and infrastructure managers, i.e.

V2I communications. The Amsterdam Group's objective is going beyond improvements achievable of current stand-alone systems and to strengthen the cooperation with all transport modes as a multimodal transport service. The prioritization on the roadmap is set to Day-One-Applications to be implemented in the first phase of deployment starting with 2015.

Many of the mentioned projects/organizations have strong cooperation and/or are participating in one of the other projects.

3. V2X COOPERATIVE SYSTEMS

3.1. SYSTEM OVERVIEW

Fig. 1 gives an overview about an end-to-end V2X cooperative system. The main physical parts of the system in top down order are: TMC, RSU, and OBU.
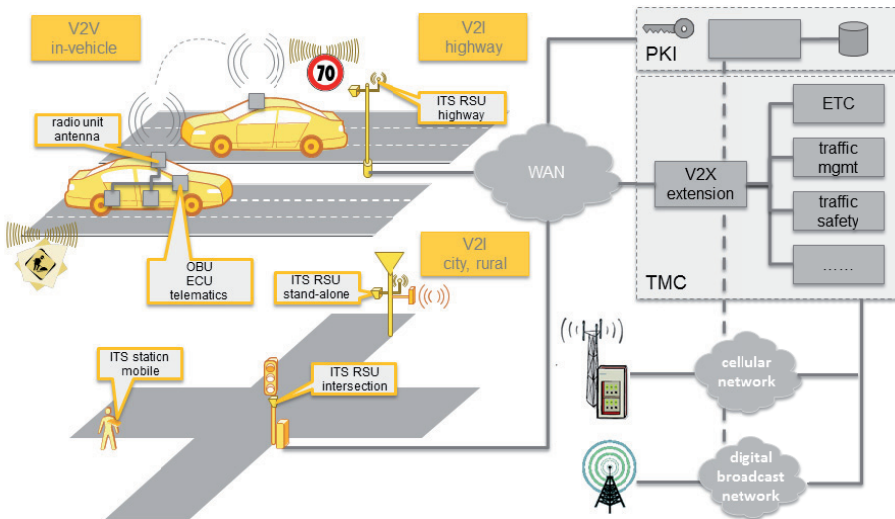

Fig. 1. V2X cooperative system architecture, Ref. 1

On the right side of Fig. 1 the TMC is depicted. There are many application-oriented subsystems: Electronic Toll Collection (ETC), traffic management (mgmt), traffic safety, etc.. In order to offer the users (drivers) also further comprehensive information (e.g. actual public transportation time schedule, weather forecast on your route) external data sources from other providers can be connected to the TMC. The TMC is connected via a Wide Area Network (WAN) to the RSUs that are transmitting (receiving) messages to (from) the vehicles in their coverage area via the V2I link. It can be distinguished between a highway

area and a city or rural area where different services are prioritized, e.g. intersection control (traffic light signal phase transmission, intersection collision warning) in a rural area. Further the responsibilities for operation are typically different for the highways and the city, i.e. it may be necessary to operate two different TMCs with certain interconnection and information exchange.

In the vehicle an OBU (with external or internal antenna) receives the messages from the RSUs. The main two kinds of OBUs are aftermarket OBUs (can be easily installed after the sale of the vehicle) and in-vehicle integrated OBUs (integrated by the car manufacturer). The OBU is also able to transmit messages to the RSU (e.g. sensor data that are collected on the road) and to communicate with other vehicles (V2V link). This makes it also possible to forward messages from the RSU via multi-hop over several vehicles to a specific area or vehicle where no RSU communication coverage is available. An in-vehicle integrated OBU is connected via the vehicular Controller Area Network (CAN) bus to the Electronic Control Unit (ECU). In this case enhanced sensor data may be provided to the infrastructure and other vehicles (e.g. steering wheel angle, anti-lock breaking system, windscreen wiper status, slippery road) especially for safety-related applications.

Complementary to the 5.9 GHz based V2X communication system, cellular systems and digital broadcast systems can be used for the communication with the vehicles.

In order to protect the safety-critical messages it is necessary to implement mechanisms that secure the messages from attacks like spoofing, alteration, and replay. Further it is necessary to protect the privacy of each driver. For this a Public Key Infrastructure (PKI) is implemented in the V2X cooperative system, see Fig. 1 right upper corner. A set of pseudonym certificates will be used by the RSUs and OBUs (frequently changed), in order to secure the messages and protect the privacy of the source. The security and privacy topic is not discussed in detail in this paper, but it has to be mentioned that it is an essential part of the system.

3.2. V2X COMMUNICATION TECHNOLOGIES / STANDARDIZATION

As the name V2X already states, the communication is between vehicles, V2V, and between vehicle and infrastructure, V2I, where both communication links are bidirectional. The technology for this is 5.9 GHz radio communications. The initial driving forces for the technology are the USA and Europe. The main standardization committee in the USA is the Institute of Electrical and Electronics Engineers (IEEE) - with already finalized standards for 5.9 GHz communications - and in Europe the European Telecommunications Standards Institute (ETSI) - where the standards are currently being finalized - and the European Committee for Standardization (CEN). The International Organization for Standardization Technical Committee 204 (ISO TC204) is contributing to harmonize the standards globally.

The whole story for V2X communication standardization started in USA, where the American Society for Testing and Materials (ASTM) developed the standard E 2213 for vehicle to roadside communication based on the well-known WLAN standard IEEE 802.11. Soon IEEE took over the work and developed IEEE 802.11p and the IEEE 1609.x

series of standards to specify V2X communications operating at 5.9 GHz. These set of standards is called Wireless Access in Vehicular Environment (WAVE). The US Federal Communications Commission has allocated a 75 MHz Band at 5850 – 5925 MHz. The Physical (PHY) and medium access control (MAC) layers are described in IEEE 802.11p that was merged back into IEEE 802.11 in the year 2012. The middle layers are described by the IEEE 1609.x standard series where: 1609.4 specifies multi-channel access, 1609.3 specifies network services, and 1609.2 specifies security services. On top of these layers a set of 15 messages and their format for a variety of vehicle-based applications is specified in SAE J2735. The most important message is the Basic Safety Message (BSM) which is also occasionally described as a periodic "Here I am" message. With BSM it is possible to track the position and movement of other vehicles that can be used e.g. for avoiding collisions. Complementary to the description of the syntax of the messages in SAE J2735, the communication minimum performance requirements (e.g. transmit power control, adaptive message rate control, etc.) are specified in SAE J2945.1. A well-arranged presentation of the mentioned standards can be found in Ref. 15.

In Europe the EC allocated a main 30 MHz frequency band ITS-G5A at 5875-5905 MHz, dedicated to ITS safety related applications. Further a 20 MHz band ITS-G5B at 5855-5875 MHz, dedicated to ITS non-safety applications and a band ITS-G5C at 5470-5725 MHz (a Radio Local Area Network (RLAN)) is allocated. The frequency bands are described in the ETSI standard EN 302 663. The ITS standardization in Europe is driven by the European Standardization Organizations (ESOs) ETSI in the TC ITS and CEN TC 278. Considering the ETSI TC ITS, it is separated in five Working Groups (WGs), where WG1 works on the facility layer (applications), WG2 works on the management plane and cross layer (architecture), WG3 works on the networking and transport layer, WG4 works on the access layer (radio), and WG5 works on security services. There exists a large number of European Norms (EN), ETSI Standards (ES), Technical Specifications (TS), and Technical Reports (TR) developed by ETSI for ITS that are currently in progress or already finalized. Ref. 16 gives a well-arranged overview of the European standardization of ITS.

Beside the 5.9 GHz radio communication technology, also other communication technologies are feasible for ITS cooperative systems:

- Cellular communications, e.g.
    - Worldwide Interoperability for Microwave Access (WiMAX)
    - Universal Mobile Telecommunications System (UMTS)
    - Long Term Evolution (LTE)
- Digital broadcast, e.g.
    - Digital Audio Broadcasting (DAB)
    - Digital Video Broadcasting (DVB)

These technologies can be seen as complementary technologies to 5.9 GHz communications and not as an 1:1 alternative. In contrast to these technologies, 5.9 GHz communications offers the efficient capability of direct V2V communications. Such a communication system is called Peer-to-Peer / Peer-to-multi-Peer (P2P) or ad-hoc system. Advantages of direct V2V communication (as with 5.9 GHz communication) are no mandatory infrastructure involvement, the shorter minimum delay or latency of the delivered message and the possibility of multi-hop in areas without coverage from the

infrastructure. In cellular communication systems and digital broadcast systems the communication is always handled by base stations, i.e. 100% infrastructure dependency. Cellular systems have a bidirectional link between the base station, i.e. data can be sent from the base station to the vehicle (downlink) and the vehicles can send data to the base station (uplink). Digital broadcast systems usually offer just a unidirectional link, the base station is broadcasting information (downlink). Further it has to be taken into account if the technology can cope with the high speeds of the vehicles, e.g. Ref. 17 shows that the current implementation of DVB-T2 is functioning only at slow speeds.

3.3. TRAFFIC MANAGEMENT CENTER (TMC) – SYSTEM ARCHITECTURE

The following description accords with explanations in Ref. 18. There are demanding non-functional requirements on the TMC that counts also on the complete end-to-end system and have to be considered for the design of the system architecture:

- Availability
- Robustness
- Adaptability
- Maintainability
- Flexibility/Expandability
- Performance

Availability and robustness are already very important requirements for TMCs until now, but the requirements adaptability, maintainability, and flexibility/expandability are not a big issue because of the smaller size of the existing systems. One of the goals of V2X cooperative systems is to use all equipped vehicles as mobile sensors. Each vehicle is already collecting a lot of data of their environment (e.g. rain, slippery road, etc.) and the environmental traffic (e.g. slow speed can be an indicator for a traffic congestion). This data will be collected by the RSUs and sent as Floating Car Data (FCD) to the TMC for further processing and consecutive actions.

The collected sensor data is now not only from a (limited number) of fixed installed sensors, but includes also a huge number of mobile sensors that have ad-hoc character and can appear and disappear in the whole V2X cooperative network. Further the TMC will have an interface to other systems, like public transportation, in order to collect the actual time schedule of this transportation. This means that the TMC is acting like a data ware house, because it has to collect, evaluate, process, and distribute this huge amount of sensor data.

In this case the system requirements adaptability, maintainability, and flexibility/expandability and therefore also the performance are a significant challenge for the TMC of a V2X cooperative system.

The classical traffic management functions can be separated mainly in two parts:

- Manuel traffic operator based data acquisition and manual operator decisions (more frequent)
- Automatic data acquisition, processing, and autonomous decisions (less frequent)

From the traffic operators it is known that for their manual decisions video observations of the current traffic situation are the main basis. For important traffic flow decisions, there shall be of course still the option of a manual decision, but especially the traffic information collected from all mobile and fixed sensors and from other external sources (e.g. public transportation) has to be collected, processed, evaluated, and provided to all road users automatically. Combining these different operation strategies the above mentioned system requirements are getting very important.

In order to comply to these requirements the system architecture of TMC and RSUs has to be adopted. A P2P architecture were the TMC is embedded on the same level as the RSUs would have an advantage compared to a hierarchical architecture (client-server / RSU-TMC). Following issues could be handled by such an architecture more efficiently:

- Load balancing and scalability
- Fault tolerance
- Intelligent routing
- Lifecycle management
- Effective and efficient FCD application

3.4. APPLICATIONS / USE CASES

A wide range of applications with different characteristics are currently planned or already defined, see e.g. the projects mentioned in Chapter 1. Since one of the main goals, starting the discussion of V2X cooperative systems was to improve the traffic safety, one of the most important group is the set of safety applications. However there are many other applications without a unique classification and many institutions are using their own classification sets. We may cluster them as: safety, traffic management, driver assistance, enforcement, road pricing and electronic payment, direction and route optimization, travel-related information, intermodal transportation services and general information services as point of interest and others. ETSI TC ITS defined a list of basic applications and classified them in ETSI TR 102 638, Ref. 19:

- Cooperative/Active road safety
  - o Driving assistance – cooperative awareness
  - o Driving assistance – road hazard warning
- Cooperative traffic efficiency
  - o Speed management
  - o Cooperative navigation
- Cooperative local services
  - o Location based services
- Global internet services
  - o Community services
  - o ITS station (means RSU and OBU) life cycle management

As the name already indicates the main objective of the application class *cooperative/active road safety* is to improve the road safety. Examples of use cases for the

application *cooperative awareness* are *emergency vehicle warning* and *intersection collision warning*. Use case examples for the application *road hazard warning* are *wrong way driving warning* and *signal violation warning*. Beside the main objective safety for this application class it may also offer other benefits that are not directly associated with road safety.

The main objective of the application class *cooperative traffic efficiency* is to improve the traffic flow that would increase also the energy efficiency. Examples of use cases for this application class are *traffic light optimal speed advisory* (application: *speed management*) and *in-vehicle signage* (application: *cooperative navigation*) – displaying the static as well as the dynamic traffic signs in the vehicle.

The application classes *cooperative local services* and *global internet services* offer commercial or non-commercial applications as on-demand information, i.e. infotainment, comfort, and vehicle or service life cycle management. In this case the applications of *cooperative local services* are provided from within the ITS network infrastructure and applications of *global internet services* are offered by 3rd party providers.

The Amsterdam Group Ref. 14 is currently defining a set of Day-One-Applications (mainly for V2I communications) that shall be available in the initial V2X cooperative systems deployment starting in the year 2015.

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V2X SYSTEMY WSPÓŁDZIAŁAJĄCE – NA DRODZE DO ITS-U NOWEJ GENERACJI

Streszczenie: Po kilku latach intensywnych badań i standaryzacji, zarówno w Europie, jak i w Ameryce Północnej, współdziałające systemy oparte na komunikacji pojazd z pojazdem (V2V) oraz pojazd-infrastruktura (V2I) -czyli generalnie (V2X) - wchodzimy w fazę pierwszych wdrożeń. Została potwierdzona możliwość zastosowania podstawowej technologii bezprzewodowej komunikacji 802.11p IEEE i na całym świecie jest przygotowywane wdrożenie fazy testowania w warunkach eksploatacyjnych (FOT).

W celu spożytkowania znaczących udoskonaleń w zakresie bezpieczeństwa ruchu i wydajności dzięki wprowadzaniu komunikacji V2X , system musi funkcjonować niezawodnie przy dużych obciążeniach ruchu gwarantując istotną poprawę bezpieczeństwa oraz możliwości biznesowe dla wszystkich interesariuszy.

Dodatkowo, sposób działania systemu V2X wymaga nowych metod zarządzania danymi w centrach zarządzania ruchem (TMCS). TMCS musi przetwarzać duże ilości dynamicznych danych w czasie rzeczywistym, w celu zbierania tych danych z określonych czujników i przekazywania ruchowych informacji lokalizacyjnych w sposób dynamiczny uczestnikom ruchu. Dokument przedstawia aktualny status bieżących projektów, stanu standaryzacji i architekturę systemów współpracujących V2X.

Słowa kluczowe: komunikacja V2X, ITS , współdziałające systemy, V2V, V2I, WAVE, ITS-G5