An ADAS Design based on IoT V2X Communications to Improve Safety

Case Study and IoT Architecture Reference Model

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Abstract: Several technologies are used today to improve safety in transportation systems. The development of a system for drivability based on both V2V and V2I communication is considered an important task for the future. V2X communication will be a next step for the transportation safety in the nearest time. A lot of different structures, architectures and communication technologies for V2I based systems are under development. Recently a global paradigm shift known as the Internet-of-Things (IoT) appeared and its integration with V2I communication could increase the safety of future transportation systems. This paper brushes up on the state-of-the-art of systems based on V2X communications and proposes an approach for system architecture design of a safe intelligent driver assistant system using IoT communication. In particular, the paper presents the design process of the system architecture using IDEF modeling methodology and data flows investigations. The proposed approach shows the system design based on IoT architecture reference model.

1 INTRODUCTION

In the recent years a lot of efforts have been made to improve traffic safety. But transportation-related fatalities and injuries due to road accidents are constantly growing. Therefore improvement of driver assistance is an urgent task.

A lot of efforts have been made to face safety problems in the transportation systems. Avenues of research and development of automotive industry are directed towards a driver assistance system, active control and safety mechanism. Today we can see a lot of on-board control systems (in-vehicle systems) thanks to investigations of automotive industry (Audi, BMW, Daimler, General Motors, Ford, Honda, Mercedes-Benz, Nissan, Opel, PSA, Toyota, Volkswagen, Volvo).

In-vehicle safety technologies presented by different kinds of passive and active protection mechanisms (van Ratingen, 2015): warning systems; car robust control systems; emergency braking systems; automatic parking systems, etc. According to Khan (2016) the main sensors of ADAS architecture are Camera, Lidar, Radar, ultrasonic sensor, IR sensor, GPS. For example, Lussereau et al. (2015) describe the ADAS project of INRIA Rhone-Alpes and Toyota Europe, which uses high-resolution camera, stereo camera, two Lidars, GPS with IMU.

Moreover, the information from out-vehicle sensors can be used in order to improve the road safety along with the information from in-vehicle sensors. Therefore, governments and the business support investigation of Intelligent Transportation Systems (ITS) and vehicle ad-hoc networks (VANET) (European Parliament Directive 2010/40/EU 2010, Stübing et al. 2010, Wieker, H et al. 2009). Mostafa (2011) notes that VANET connects cars between each other and with the current infrastructure to decide safety issues. Wieker et al. (2009) defines the main purpose of ITSs like the traffic management: prevention of traffic congestions and warning drivers. ITSs can provide regulation of the traffic flow velocity, the traffic lights switching, driver notification, electronic payments, real-time road mapping, route optimization and adaptation to specific weather conditions.

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A number of partnerships and associations have been created recently to develop ITS: Intelligent Transportation Society in USA, ERTICO-ITS Partnership (2016) in Europe, etc. 'The Network of National ITS Associations' website (2016) refers to 27 member-organizations. In the field of VANET the associations are Car2Car Communication Consortium (C2C-CC) in Europe (Papadimitratos et al. 2009), Vehicle Safety Communication Consortium (VSCC) in United States and Advanced Safety Vehicle (ASV) in Japan. Different ITS and VANET projects were developed: CVIS, SIM-TD (Germany), COMeSafety, PRE-DRIVE C2X, CVIS, SAFESPOT, COOPERS, SEVECOM, Network on Wheels (NoW), ACTIV (Germany), CVHS (UK), IVSS (Sweden), Adaptive (EU), Autonet2030 (EU) (Papadimitratos et al. 2009, Stübing et al. 2010).

Vehicle communication is an important part of ITSs and VANETs and the basis of autonomous cars. In 2015 Massachusetts Institute of Technology has choose V2V communication as one of its Ten Breakthrough Technologies of 2015. Moreover, Zhang (2015) and Mostafa (2011) have shown that the use of V2X communication instead of Vehicle-to-Vehicle (V2V) provides a number of improvements. The V2X can be uses to obtain various kinds of infrastructure information about dangers and content information, not directly related to cars.

But there is a number of issues that need improvement to get further enhanced safe driving systems. First of all, ADAS systems are embedded only in some models of car. In-vehicle, VANET and ITS systems are mostly separated, using different technologies and standards, their own designed microchips. Some of them have no connection with infrastructure (V2I), some of them even have no V2V connection. It is therefore important to investigate mechanisms in order to combine different vehicle systems. It could be a huge step forward and will expedite their implementation. As well as development of the systems using the same Standards and reference model are important issues for the future vehicle infrastructure.

In this paper is proposed an ADAS design approach using methodologies IDEF and data flow analysis, in order to get objectives: to improve traffic safety and to face existing problems. We propose cooperative DAS architecture, which taking into account most of common equipment currently available in cars: car DVR, cameras, navigators and smartphones. Also we updated system with new vehicle communications technologies based on Internet of Things (IoT) and ensure its comparability with other systems by using actual Standards. We proposed an approach in order to integrate IoT into V2X communication by using IoT reference model and modern Standards. The approach is demonstrated on the case-study example.

2 MODERN COMMUNICATION TECHNOLOGIES AND ISSUES

Vehicle communications have their roots in *machine-to-machine (M2M) communications* technologies. Nowadays M2M concept came out of the scope of communication between devices of the same type, and developed into a broader and more modern concept *Internet of Things (IoT)*. The IoT allows connecting different types of physical objects or "things" to the network via the Internet protocols (IP) to enable it exchanging data with other connected devices, infrastructures, and operators (Vasseur 2014), (Al-Fuqaha et al. 2015). Each "thing" is uniquely identifiable through its embedded computing system and it is able to interoperate within the existing Internet infrastructure.

The most important advantage of IoT is using IP to connect devices via Internet. It is very important for the possibility to integrate different IoT systems (government, transport, medicine, education, energy etc) with regards to more global *Internet of Everything concept (IoE)*. Let's note the revolutionary meaning of the IoT and IoE concepts for our life. In the future IoE should combine all our devices, gadgets, vehicles, biochips. IoT/IoE technologies are the essential building blocks of the future information society (Vasseur 2014).

There are a lot of issues in the transformation vehicle systems according to IoT concept. Most of the existing solutions are isolated from each other and seem to be "INTRAnet of Things" but not "INTERnet of Things" (Bassi 2013). That's why formulating new approach for design of the IoT system architecture and building IoT systems according to modern Standards are important issues.

3 CASE STUDY

3.1 An Approach to the System Architecture Design

The proposed system is focused on the road safety mission. In the architecture modeling process we have used Integration Definition (IDEF) modeling methodology and Data Flow analysis. IDEF is a set of powerful modeling methods and modeling languages most used to design and analyze highly complex systems. In Fig. 1 system being developed presents in function modeling language (IDEF0 Diagram). The input of the function is issues and sensors data. The output of the function is our main objective: in result we would have improved safety.

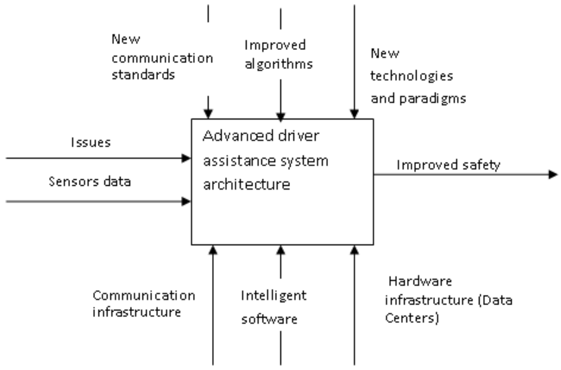

Figure 1: Function model (IDEF0 Diagram).

The control of the IDEF0 function is the new technologies and new standards. We supposed the new technologies are IoT/IoE, Cloud computing. Also according with the IDEF0 control we would design architecture with modern V2V and V2I communication standards, as well as update it with IoT standards. The mechanisms of the IDEF0 function are communication infrastructure, powerful Data Centers, intelligent algorithms. We suppose to use Cloud, Fog computing to provide Big data analysis with object detection complex algorithms.

The designed system architecture is shown in Fig. 2. In order to realize V2X communication we suppose to use on-board cameras inside the car as well as infrastructure cameras network. Moreover, we use improved IoT V2X communication which allows collecting information from different kind of sensors, devices and systems - “things” in IoT: vehicles, DAS, in-vehicle and infrastructures sensors and driver`s gadgets (Laptop, Smartphone). All these “things” connected to the server (Data Center) with intelligent logic via IoT. The system has been designed according to the objective of getting a maximum standardization. On the fig. 2 the cars have reachable ITS. Usually ITS consist of Vehicle Station (VS), Road Station (RS), Road Side Unit (RSU) and Server (Stübing et al. 2010). The information from ITS and over infrastructure information became available for the driver in order to connection of the ITS station to the IoT.

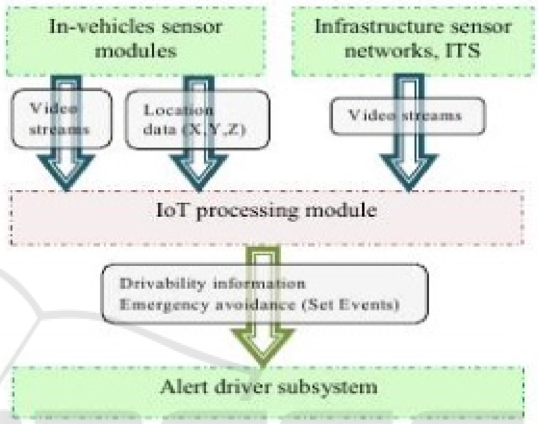

Figure 3: Data Flow Diagram for cooperated DAS.

The system is connected to the powerful Data Center via Internet. In this case can be used more sophisticated intelligent algorithms. That allows building a enhanced and low-cost client part of the system for drivability.

Data flow diagram is shown on the Fig. 3. You can see that proposed system evaluates different aspects of the traffic situation due to video and navigation data both from in-vehicle and infrastructure sensors.

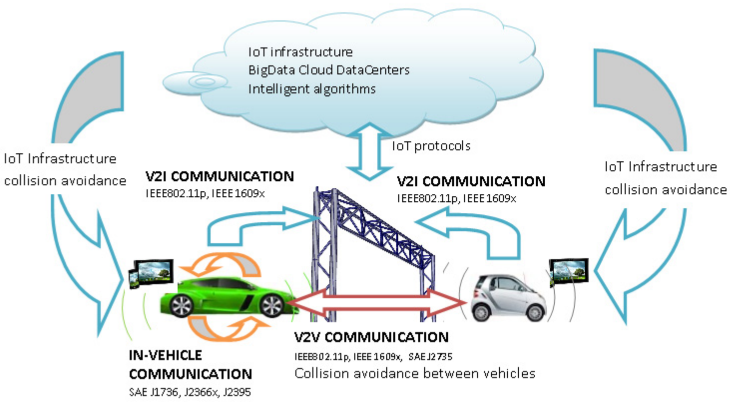

Figure 2: Designed V2X system architecture with proposed approach.

3.2 IoT ARM Development for the Designed System

We designed IoT architecture for cooperative DAS according to the standard of European Telecommunications Standards Institute (2010) ETSI 302 665 ITS and IoT Reference Architecture Model (ARM) (Bassi 2013) to ensure compatibility with other IoV decision in the future (Fig. 4). The standard ETSI 302 665 ITS presents network layers for vehicle networks, where IoT architecture have to include 4 layers: “Access level” representing ITSC`s OSI layers 1 and 2, “Networking and Transport level” representing ITSC`s OSI layers 3 and 4, “Facilities” representing ITSC`s layers 5-7, “Application level” representing layers 7.

The *IoT Management* is a semantic level of IoT process management; it describes the conceptual integration of management in IoT ARM. This level provides integration of all subsystems, different IoT component and push IoT systems from isolated «inTRAnet of things» to the Internet of things.

The *IoT Service Organization layer* describes structure of IoT services and provide possibility to control these services. Because of these two layers (IoT Management and Service Organization) we can build balanced system architecture.

The *IoT Service layer* provides data acquisition and control of the “things” (sensors and devices). It’s a different host server IoT apps (IoT services) for interaction with physical sources.

The *Virtual Entity (VE)* presents real physical objects and subjects like abstract information business model (present “things” of the real world by classes, database data representation model etc.).

Lets describe IoT ARM layers of the designed cooperated DAS.

3.2.1 Device Level: Sensors

Sensors module consists of sensors inside the car (in-vehicle sensor) and road infrastructure sensors (Fig. 5). We propose to use common devices we have in the car: navigators, car DVR, cameras, GPS, Smartphone, Tablet, existing infrastructure cameras, infrastructure road sensors and other sources of information. The most important sensors are cameras.

Navigation sensors are GPS receiver, low-cost models strapdown INS or mobile enable device with A-GPS technology.

3.2.2 Communication Layer

We consider car has a vehicle station (VS) and M2M microchip supported Dedicated Shot-Range Communication (DSRC) technology to realize V2V communication.

In Fig. 2 and 4 are shown that cars are connected each other by V2V with wireless protocols for vehicle WAVE (Wireless Access in Vehicular Environments). PSY and MAC levels of the WAVE was described in the Standard IEEE 802.11p

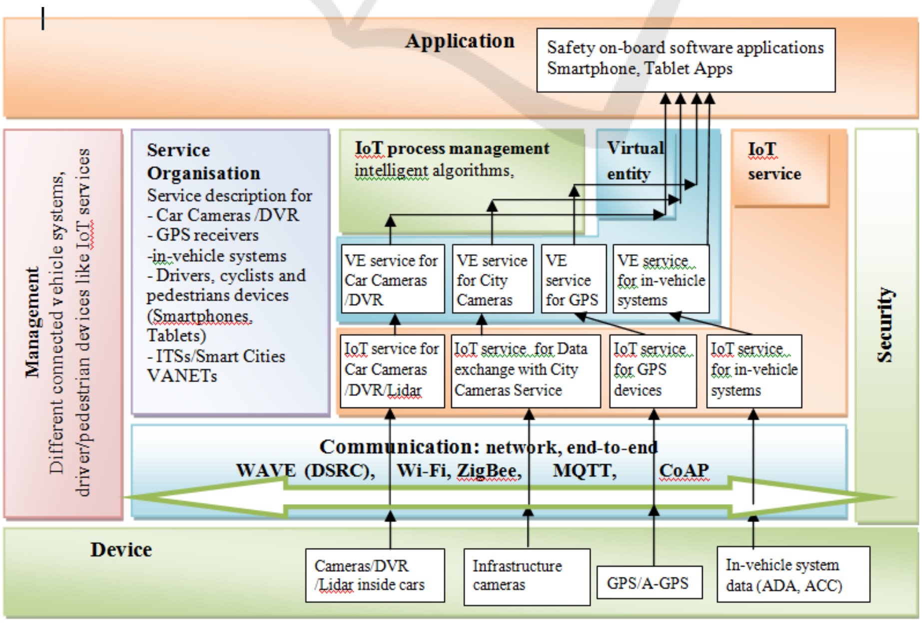

Figure 4: Proposed system ARM network levels according to ETSI standard.

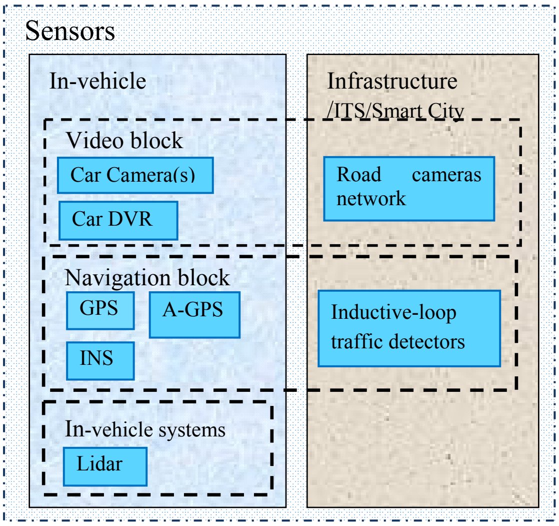

Figure 5: Device level: sensors.

(Abdeldime et al. 2014); media level data, network and transport was presented by the set of standards IEEE 1609x designed by Institute of Electrical and Electronics Engineers in 2013 and 2016; APP level was described in SAE J2735. Vehicles connected with infrastructure ITS Road station through V2I connection using IEEE 802.11 (PSY MAC Wi-Fi), IEEE 802.11p (Abdeldime et al. 2014), IEEE 802.11b (WAVE) (Al-Fuqaha et al. 2015) or IEEE 802.15.4 (Institute of Electrical and Electronics Engineers IEEE 2011) with ZigBee protocols (Herrera-Quintero et al. 2015). Road Station (RS) connects with IoT infrastructure through IoT protocols: MQTT was designed by Organization for the Advancement of Structured Information Standards (OASIS) in 2014, CoAP was designed by Internet Engineering Task Force (IETF) in 2014 and HTML/2 was developed by Internet Engineering Task Force (IETF) in 2015.

IoT based V2X communication unifies communication standards and equipment for communication between vehicles like "things" in IoT. This fact allows connecting transport systems not only between each other, but also with other existing and future systems in different spheres to realize in the future concept of Internet-of-Everything.

If vehicle or infrastructure sensor detect a potential danger, it warns other cars using WAVE communications or IoT.

3.2.3 IoT Communication with "Things"

Data transmission from the in-vehicle sensors and driver`s gadgets to the IoT can be direct for internet enable devices. For devices without IP support we should use special microchips. This microchip has to support IoT protocols as well as different required interfaces of the connecting "thing". For example, we can use cheap Raspberry Pi minicomputer to connect driver`s not IP camera of video recorder to the IoT.

It is need special gateways with relevant protocols in order to connect ITS, Vanets and ADAS systems to the IoT.

3.2.4 Application Level: Proposed Apps Structure for Safety Problem and Issues

A number of safety applications have already been implemented on modern cars using video cameras and radars, for example algorithms for the emergency braking assistance (van Ratingen, 2015), road line detection, map-based location, the abrupt change of car movement direction using information about speed, sharp pressing the brake pedal (Lussereau er al. 2015). Also the dangers can be recognized on the basis of the evaluation of the cars movements and drivers behavior (Cheng and Zongxin 2013).

The designed system based V2X communication can provide more high level of safety in the driving assistance system by using external information: assistance during the passage of the intersection; help when turning; safe separation from oncoming vehicle; warning when leaving for highway; detection of obstacles on the road; information about the traffic accidents; warning emergency braking; warning rear collision (e-stop signal); warning lane change; warning about bad weather conditions; information on road signs; notification of an approaching motorcyclist (Fig. 6).

But these systems cannot see around corners. Mostly they do not connected with infrastructure and use only onboard sensors. Even if all the cars and motorcycles will be equipped with V2V, remain other road users (cyclists, pedestrians), in which this system is absent.

Designed driver assistance system based on V2X IoT communication did not present those disadvantages. Designed system provides infrastructure notification and also cyclists and pedestrians can use IoT safety apps to enjoy the vehicle safety system

However, some problems are remained. The main problem of proposed system is the low level of the distribution system, due to relatively high rates WLAN module. For effective use of the Car-to-X at least 10-15% of vehicles must be equipped with

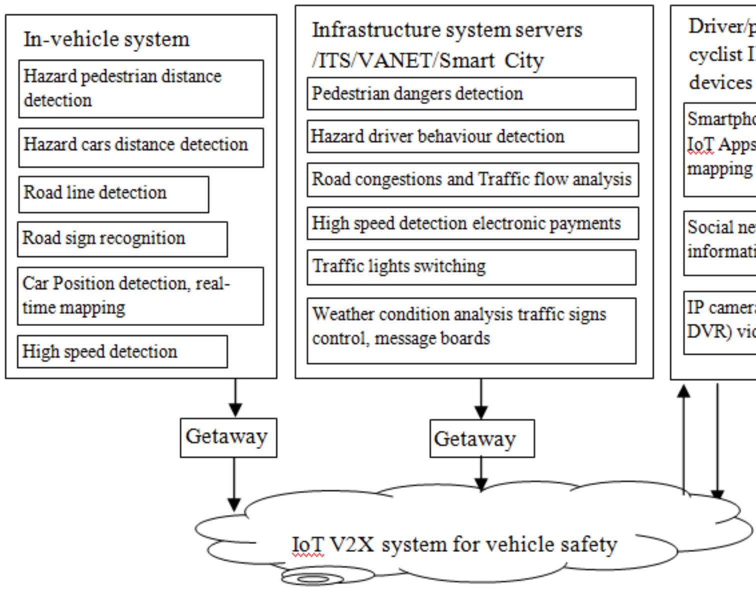

Figure 6: Application level and connection with IoT.

wireless equipment, and it's still very far away. Another problem is the low system reliability in determining dangers. When proposed system might simply overwhelm the driver of various kinds of information, from which not all are needed for movement. This, ultimately, will constantly distract the driver from his primary occupation is driving.

3.3 Application Level: Driver Alert and Notification

As soon as the vehicle or infrastructure sensors have detected a potential danger, they warn other drivers by IoT V2X system.

Smartphone/Tablet Apps provide driver alerts. Proposed system realizes end-to-end communication by mobile networks standards GSM/UMTS (3G)/LTE(4G). Mobile networks use to transmit notification to the driver alerts subsystem.

For driver alerts in ITS and VANET network on the App level and network level can use ZigBee protocol on the top of IEEE 802.15.4 (PSY level). ZigBee is a low-power WPAN. ZigBee can work with vehicle networks thanks to ZigBee network layer supports mesh ad-hoc network (also it supports point-point and stars network configurations).

By using IoT we suggest significantly simplify and integrate important functions of driver assistance to improve safety on the road.

4 CONCLUSIONS AND FUTURE WORK

We have proposed the approach to the design of the cooperative ADAS architecture and structure based on the IoT V2X communications. The proposed solution is able to collect different kinds of signals from different sensors and devices to analyze the traffic situation.

We have developed the DAS architecture according with IoT reference architecture model and modern communication standards. Therefore, the proposed system design is ensure comparability with different kind of existing in-vehicles and V2I systems. We are confident that it will allow the use of important information from other networks for road safety in the future. It can be Smart grids, VANET, mobile networks, and even business, education or social networks. It was shown the way to present common driver`s sensors and gadgets in the car like “things” in the IoT. These common devices can give us a lot of information to improve safety.

In the further work we presume enormous opportunities to enhance safety and provide for the driver wide range warning information like results of Big data intelligent analyze, event notification, significant context information would be available. It can be danger driver alerts, access to appropriate infrastructure information about current road, congestions, significant event from infrastructure or other cars, potential danger from infrastructure or other cars for driver alerts or safe active control systems. IoT-based V2X communication also has great potential to improve automated vehicle.

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