A Safe Intelligent Driver Assistance System in V2X Communication Environments based on IoT

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A Safe Intelligent Driver Assistance System in V2X Communication Environments based on IoT
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Research is dedicated to the father of my friend
and all people died on the road
Memory eternal

Abstract

In the modern world, power and speed of cars have increased steadily, as traffic continued to increase. At the same time highway-related fatalities and injuries due to road incidents are constantly growing and safety problems come first. Therefore, the development of Driver Assistance Systems (DAS) has become a major issue. Numerous innovations, systems and technologies have been developed in order to improve road transportation and safety. Modern computer vision algorithms enable cars to understand the road environment with low miss rates. A number of Intelligent Transportation Systems (ITSs), Vehicle Ad-Hoc Networks (VANETs) have been applied in the different cities over the world. Recently, a new global paradigm, known as the Internet of Things (IoT) brings new idea to update the existing solutions. Vehicle-to-Infrastructure communication based on IoT technologies would be a next step in intelligent transportation for the future Internet-of-Vehicles (IoV).

The overall purpose of this research was to come up with a scalable IoT solution for driver assistance, which allows to combine safety relevant information for a driver from different types of in-vehicle sensors, in-vehicle DAS, vehicle networks and driver`s gadgets.

This study brushed up on the evolution and state-of-the-art of Vehicle Systems. Existing ITSs, VANETs and DASs were evaluated in the research. The study proposed a design approach for the future development of transport systems applying IoT paradigm to the transport safety applications in order to enable driver assistance become part of Internet of Vehicles (IoV). The research proposed the architecture of the Safe Intelligent DAS (SiDAS) based on IoT V2X communications in order to combine different types of data from different available devices and vehicle systems. The research proposed IoT ARM structure for SiDAS, data flow diagrams, protocols.

The study proposes several IoT system structures for the vehicle-pedestrian and vehicle-vehicle collision prediction as case studies for the flexible SiDAS framework architecture. The research has demonstrated the significant increase in driver situation awareness by using IoT SiDAS, especially in NLOS conditions. Moreover, the time analysis, taking into account IoT, Cloud, LTE and DSRS latency, has been provided for different collision scenarios, in order to evaluate the overall system latency and ensure applicability for real-time driver emergency notification. Experimental results demonstrate that the proposed SiDAS improves traffic safety.

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List of abbreviations/Vocabulary

6LoWPAN – Ipv6 over Low power Wireless Personal Area Networks

ABS – automobile Anti-lock Braking System

ACC – automobile Adaptive Cruise Control

ADAS – Advanced Driver Assistance System

API – Application Programming Interface

ARM – Architecture Advanced (Acom) RISC Machine

AWD – all-wheel-drive (4WD)

CDC – Cloud Data Center

CISC – Complex Instruction Set Computing

CoDAS – Cooperative Driver Assistance System

CUDA – Compute Unified Device Architecture (parallel computing platform NVidia)

D2S – Device-to-Server communication

DAS – Driver Assistance System

DB – Database

DBMS – Database Management System

DSRC – Dedicated Short Range Communication

DVR – Digital Video Recorder (car camcorder)

EBS – automobile Emergency/Electronic Braking System

ESC – automobile Electronic Stability Control system

IDE – Integrated Development Environment

IDEF – ICAM (Integrated Computer-Aided Manufacturing) DEFinition

IoT – Internet-of-Things

IoE – Internet-of-Everything

IP – Internet Protocol

IPv4 – IP version 4

IPv6 – IP version 6

IT – Information Technologies

ITS – Intelligent Transportation System

GPU – Graphical Processor Unit

HOG – Histogram of Oriented Gradients

M2M – Machine-to-Machine communication

MQTT – Message Queue Telemetry Transport (IoT protocol)

NAS – Network Attached Storage

NAT – Network Address Translation

NGN – Next Generation Networking

NoSQL – Not only SQL database;

OpenCV – Open Source Computer Vision API

OSI model – 7 level Open Systems Interconnection model

PAN - Personal Area Networks

RAID 1-6– Redundant Array of Independent disks

RISC – Reduced Instruction Set Computing

S2S – Server-to-Server communication

SAN – Data center Storage area network

SIMD – Single Instruction Multiple Data

SOA – Service-Oriented Architecture

SVM – Support Vector Machine

SUN – Smart Ubiquitous Networks

TCP – Transport OSI Transmission Control Protocol

TCP/IP – stack;

UDP – User Datagram Protocol (TP OSI)

V2V – Vehicle-to-Vehicle communications

V2I – Vehicle-to-Infrastructure communications

V2P – Vehicle-to-Pedestrian communications

V2X – Vehicle-to-X communications

VANET – Vehicular ad hoc network

VC – Vehicle communications

VM – virtual machine

VRU – Vulnerable Road Users

WAVE – Wireless Access for the Vehicle Environment (PSY/MAC IEEE 802.11p)

WPAN – Wireless Personal Area Network (PSY/MAC IEEE 802.15.4)

x86 / x86-64 – common CISC processor architecture of Personal Computers (modern processors are CISC with RISC core)

IA64 – true 64 bit processor architecture (VLIW)

VLIW – computer architecture Very Long Instruction Word

UML – Unified Modeling Language

1. Introduction

Recently, the main efforts of governments have been concentrated on the construction of the intrastate road and interstate highway systems. At the same time, vehicles and cars had been developing and improving very quickly by the automotive industry. Highway systems and roads enable growth of the economy, mobility of people and goods.

But transportation-related fatalities and injuries due to road incidents are constantly growing and claim more than 1.2 million lives each year in 2013 [1]. In 2017, this number is about 1.3 million and 20 – 50 million sustain non-fatal injuries. Over 3 400 people die on roads every day. Road accident is a leading cause of death among young people aged 15 to 29 years [2].

Over the last few years a lot of effort has been made to improve traffic safety. Two different directions have been taken.

From one side, the car industry has developed on-board systems (in-vehicle systems) for cars. Many driver assistance functions have become an everyday tool, such as anti-lock braking system (ABS), Electronic Stability Control (ESC), automatic parking, blind spot monitoring, rear view or road line displaying on the onboard car computer, obstacle detection, on-demand all-wheel-drive (AWD). Avenues of research and development of the automotive industry are directed towards driver assistance systems and safety mechanisms. A lot of active control systems, driver assistance, warning systems and protection mechanisms have been developed. Significant progress has been made due to investigations of automotive industry (Audi, BMW, Daimler, General Motors, Ford, Honda, Mercedes-Benz, Nissan, Opel, PSA, Toyota, Volkswagen, Volvo). In-vehicle systems can contain rear view cameras; warning system; passive and active protection systems; car robust control systems; collision damage reduction braking systems; automatic parking etc.

From the other side, government, scientists, broadcasters and IT companies have started to develop and implement different transportation technologies to provide the driver with infrastructure information.

In 1986 in the USA, a group of scientists and state transportation agencies started to discover the new paradigm for the transportation [3]. The research was aimed at the safety problem, congestion and uses the current highway and road infrastructure. As a result, Intelligent Vehicle Highway Systems (IVHS) concept was invented in Texas in 1990. Later this concept was renamed to Intelligent Transportation System (ITS) [3]. The idea was that the current infrastructure could be connected with advanced technology (computing networks, sensors, information systems, intelligent algorithms). ITSs aim to reduce traffic problems and congestions. These systems also use roadside sources of information from infrastructure to normalize traffic and improve safety on the road. The ITS concept became an integral part of the Intermodal Surface Transportation in 1991.

Along with ITSs, ad-hoc vehicle networks (VANETs) were investigated. Their purpose was to connect cars with each other through a spontaneous creation of the vehicle wireless network in the current environment. VANETs seek to resolve the safety issues and assistance to pass road intersections.

Different ITS associations including research institutions, the car industry, and businesses are being sponsored by governments [4]. Many companies joined the consortium for the consolidation of efforts Car-to-Car Communication Consortium, ERTICO-ITS in Europe [5], The Network of National ITS Associations [6] and in the USA Intelligent Transportation Society (ITS) etc.

Since then many ITS and vehicle network projects have been started with business and government assistance [7]. ITS systems based on car-to-car and car-to-infrastructure communications are considered to be the key technology for safe and intelligent transportation in the future.

Vehicular communications (VC) have been developed as a significant part of ITSs and VANETs. Microchip and communication protocols between cars have been investigated. Communication between vehicles is called Vehicle-to-Vehicle (V2V) or Car-to-Car (C2C) communications. Communication between cars and infrastructures is called Vehicle-to-Infrastructure (V2I) or Car-to-Infrastructure (C2I). Communication among cars and among cars and infrastructure are called Vehicle-to-X (V2X) of Car-to-X (C2X).

But there are many issues that need to be improved to further enhance the use of safe driving systems. First of all, both in-vehicle and vehicle networks are not widespread and present on some particular models of new cars, as well as infrastructure for vehicle networks has not yet been built. It is difficult to find solutions for old model of cars. For effective use of the V2X at least 10-15% of vehicles must be equipped with wireless equipment, and it's still very far away. Many technologies are not commercially available. Some available systems were not yet common and often relatively expensive.

The second major problem is that all these systems are based on different technologies, manufactures and standards. This problem is aggravated by the fact that all these systems are based on different technologies and standards, and use their own produced microchips, different types on-board equipment and car computers. In practice, even ITSs based on the same standards are disparate, their implementation is limited to one of more particular cities. Their implementation will take a long time, especially in underdeveloped countries. Some Vehicle systems have no connection with infrastructure (V2I), some of them have no connection between vehicles (V2V). Often automotive companies design commercial proprietary projects and use their own designed special microchips or cards, on-board computers different from others car models. Mostly, the automotive industry is interested in improving their own car models and to making them more attractive than their competitor`s production.

The unification, standardization and widespread implementation of driver assistance systems and vehicle networks are the greater issues of national and international concern. And nowadays, many efforts are currently done by governments in order to unite efforts of the industry, academia, research institutions, media and IT business and solve these two major issues [8].

A third important issue is that information technology and sensor networks have reached a new level (Internet of Things paradigm, Cloud computing, Big Data analysis). Therefore, Driver assistance systems (DAS) and V2X communication require updating with the new technologies.

Actually, V2V communication has grown from the concept of communication between devices, so called machine-to-machine (M2M). In fact, V2V is the M2M communication with regards to vehicles. M2M (machine-to-machine) is technology for communication between devices of the same type generally without human participation. There are different ways to connect devices: direct communication by DSRC (radio wave), microchips embedded in the device with special M2M protocols, IP based communications, wireless and wired systems. M2M communication is used in different fields: mobile communication, industry, transportation, logistics, Smart Grid etc. M2M devices can be machines, vehicles, phones, sensors, cameras.

With the development of M2M, concepts have came out of the scope of communication between devices of the same type, and were reborn as a modern concept of the Internet of Things (IoT). And now there has been a shift in technology on the side of the IoT. Therefore, M2M and V2V became the part of the more global concept of IoT. We believe that in the near future ITS will be built using IoT based communications.

The Internet-of-Things (IoT) is a technology which allows for the connection of different types of physical objects or "things" to the network via the IP to enable those exchanging data with other connected devices, infrastructure and IoT platform. “Things” in the IoT unlike M2M can refer to a wide variety of objects such as heart monitoring implants, biochip transponders on farm animals, vehicles with embedded sensors, phones. Each “thing” is uniquely identifiable through IPv6 addressing and is able to interoperate with Internet infrastructure because its low power embedded computing system with communication module.

One of the major differences between M2M and IoT is that M2M connects one type of devices. IoT connects different type of devices. Another difference is that M2M uses different communication protocols and technologies; IoT uses IP protocol to connect devices through Internet.

The concept Internet of Everything is a global variant of IoT. IoE seeks to connect people, things, data and process.

Moreover, IoT/IoE is the part of the SUN model (Smart Ubiquitous Networks), which will connect IoT/IoE networks with existing Vehicle ad hoc networks (Vanet), Manet (Mobile network), NGN and nanonetworks.

The use of IoT architecture and IoT communication is very important for the further integration of driver assistance system with others IoT systems: government, transport, medicine, education, energy; as well as with people, data, NGN with regards to more global Internet-of-Everything (IoE) and SUN concept. Let’s note the revolutionary meaning of the IoT and IoE concepts for our life. In the future SUN and IoE should to combine all our devices, gadgets, vehicles, biochips. IoT/IoE/SUN technologies are the essential building blocks of the future information society.

2. Problem Statement

Ensuring road safety is the major task for any participant in the movement, as pedestrians and drivers. Besides, the problem of road safety is one of the priority tasks of the government.

A number of systems were investigated for traffic safety. In-vehicle systems like Driver Assistance Systems (DASs) and vehicle networks like ITS and VANETs should provide drivers with full, reliable and timely warning on the road dangers. Hazard notification should be available in any car.

However, DASs and vehicle network communication modules are embedded only in particular car models. Even if these systems are available in the car, they have low reliability in determining dangers. All these systems tended to be expensive for drivers and require additional equipment. And they usually do not have easy access for any drivers through private gadgets.

But a maximum traffic safety is needed today, because now on the road thousands of people are dying. A road safety problem is on the rise [1].

In-vehicle systems, DASs, vehicle networks and driver`s gadgets and sensors are not interconnected. From any of these systems/devices we can receive critical information about dangers and significantly increase driver situation awareness. The proposed solution of the Safe Intelligent DAS (SiDAS) based on IoT V2X communications allows for the interconnection of different systems, and the obtaining of information from infrastructure and vehicle networks. This research proposes structure and algorithms for ADAS system, making it possible to capture and process Big data flows using powerful Cloud Data Center from different kinds of sensors, devices, vehicles and transport systems to improve the event notification of the road traffic hazards. The system is able to handle the most common equipment in the car including driver gadgets (Smartphone, Tablet, Navigators, car Digital Video Recorders, car cameras etc). The study pays a lot of attention to the pedestrian detection circuit in the SiDAS as the most unprotected road users – pedestrians.

Therefore, problem statement: to design interconnected architecture and algorithms for SiDAS, providing integrated data to road users in order to contribute to safety issues.

3. Relevance

This research is devoted to the building of information system using V2X communication for safe drivability. This topic is very relevant. According to a report of the World Health Organization growth in the number of those killed in road accidents is becoming a more serious problem [1].

Therefore technologies for the traffic dangers avoidance are coming to the fore. Scientists believe that one of the most promising technologies for traffic safety is Vehicle Communications. In 2015 of all the technologies concerning the automobile and the automotive world, it is V2V communication that the Massachusetts Institute of Technology has identified as one of its Ten Breakthrough Technologies of 2015 [9]. The MIT Technology Review has written that V2V communication «is likely to have a far bigger and more immediate effect on road safety». Besides, beyond scientific interest, this research could have wide practical application.

4. Objectives and Tasks of the Research

The main objective of the study has been to explore ways of including in-vehicle and infrastructure information to address safety concerns.

The tasks of the research are:

1. Investigate existing driver assistance systems and vehicle networks in order to improve safety issues.
2. Develop SiDAS architecture, which able to collect various type of information via from multiple sensors and multiple systems working with various protocols.
3. SiDAS architecture design using IoT Architecture Reference Model and Standards.
4. Navigation and video data acquisition via IoT protocols. Develop a solution for data analysis and fusion using Cloud computing, Big data opportunities.
5. Develop algorithms for the analysis of the traffic situation.
6. Develop advanced mechanisms of the driver alert via driver gadgets connected to IoT services.

5. Evolution and New Trends of Vehicle Systems

Various technologies are used for data acquisition from vehicle and infrastructure sensors. Let us go through them and describe evolution of Vehicle Systems (VS) and Vehicle Communication (VC).

6.1. Evolution of Driver Assistance Systems (DAS): from In-vehicle Systems to Cooperative

Driver Assistance Systems (DASs) is a set of advancements features that are helping during the driving process, providing increased safety and guarantee improved driving comfort. There are active and passive DAS mechanisms. Different DAS was available mostly in high cost luxury vehicles. Nowadays, the implementation of DAS applications on the entry level cars is a longer-term trend. And DAS development goes beyond ABS, ESC, speed assistance and rear view camera, which became common.

The development of DAS is moving towards highly automated driving and autonomous driving [10]. So called Advanced/Automated Driver Assistance System (ADAS) is a modern type of DAS (Fig. 1). ADAS is highly complex system, implying highly automated features. Some of the features [11]:

- Automated emergency/electronic braking system (AEBS),
- Lane departure warning (LDW),
- Automatic parking,
- Blind spot monitoring,
- Automatic drive beam.

ADAS usually contains sensors, perception, planning and operation layers [10]. The main sensors usually include front-view and rear camera, LIDAR, long/mid-range RADAR, ultrasonic sensor, infra-red sensor (IR) [11]. ADAS has Electronic Control Units (ECUs), which provide data acquisition from a set of sensors [11]. Vision and Perception layers can include object detection algorithms, moving object estimation, object tracking, object mapping, 3D reconstruction [10].

Recently, many researchers have been provided on the topic of ADAS. The authors of the paper [11] propose three new features: Intelligent Powered Doors, Novel Estimated Time of Arrival (ETA) and Advanced overtake assistance.

Adaptive Cruise Control (ACC) is an important existing ADAS active system in the implementation phase. The optimization of criteria for ACC and its simulation in real world scenarios has been studied in the paper [12].

A number of programs are available for the test of ADAS features implementation on the different models of cars:

- European New Car Assessment Programme (Euro NCAP) [13],
- Unites States New Car Assessment Programme (US NCAP).

In 2014 Euro NCAP introduced test protocol for Autonomous Emergency Braking system (AEB) [10] and Forward Collision Warning (FCW). In the paper [14] provided large scale analysis and simulations of AEB and FCW for Euro NCAP and US NCAP tests in different scenarios. Thereby, *the first trend* of DAS is that *ADASs tend to become more complex and autonomous systems*.

ADAS chiefly implies using in-vehicle sensors for automation (sensors, located inside the car). In-vehicle stand-alone DAS can help to maintain a safe speed and distance due to ACC or AEB, drive within the lane due to LDW, avoid overtaking in critical situations due to ESC. However, substantial benefits could be derived from the use of communication technologies. *The second trend of DAS is using Vehicle Communication (VC) to obtain extra information* in order to increase reliability of driver assistance.

Recently, a number of researches have been carried out on the topic of DAS/ADAS using the data from external sources of information (infrastructure data, data from other cars) [11] [15] [16]. In particular, the systems using data from other vehicles (vehicle networks) over vehicle communication refers to as Cooperative Driver Assistance System (CoDAS) [15] or Cooperative ADAS (C-ADAS) [16] (Fig. 1).

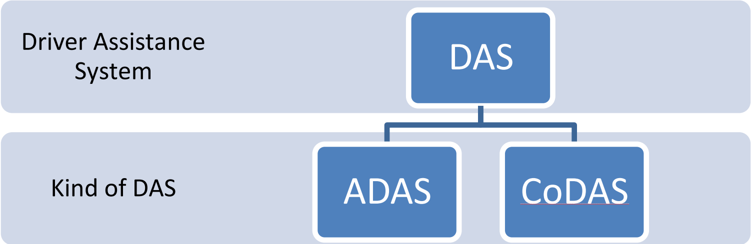


Fig. 1. Types of DAS

CoDASs offer solutions for cooperative intelligence both for full and partially autonomous vehicles [15]:

- cooperative frontal collision avoidance (CFCA),
- cooperative adaptive cruise control (CACC),
- cooperative lane merge (CLM),
- cooperative overtaking collision prediction (COCP),
- cooperative intersection management (CIIM)/intersection collision prediction.

Therefore, nowadays ADAS and CoDAS tend to use communication technologies between vehicles and with infrastructure devices. More and more, DAS and vehicle networks are becoming integrated [17].

6.2. Evolution of Vehicle Networks

External information sources, in addition to information from internal car sensors, enable to improve significantly the road safety. An infrastructure data about traffic situation, weather conditions, as well as other vehicles and road users have assumed an important role as sources of external information. Data consolidating efforts from road infrastructures, vehicles result in the development of *Vehicle Networks.* Vehicular networks are a type of network in which vehicles and roadside units are the communicating nodes, providing each other with information, such as safety warnings and traffic information. Generally, vehicular networks can contain two types of nodes: vehicles and roadside stations.

These networks help to improve road safety, traffic efficiency, transportation times, fuel consumption and driving pleasure. As a cooperative approach, Vehicular networks can be more effective in avoiding accidents and traffic congestions than if each vehicle tries to solve these problems individually [18]. Vehicular Networks are considered as systems able to provide safe and intelligent mobility in the future both for autonomous and common vehicles.

Currently, a wide range of organizations, including public transport and educational institutions in the U.S. and Europe, car manufacturers (Audi, BMW, Daimler, General Motors, Ford, Honda, Mercedes-Benz, Nissan, Opel, PSA, Toyota, Volkswagen, Volvo), manufacturers of electronic components (Bosch, Continental, Siemens) and other companies are working on the development and improvement of Vehicular Networks.

6.2.1. ITS

Firstly, governments developed, planned, and built the highway systems. Then highway system was being built a set of disadvantages were exposed: highway-related fatalities and injuries; traffic congestion, especially in urban zones; the energy consumption and ecological problems. Since then, safety issues began to emerge as the global problem.

As early as 1986, a group of scientists, state transportation agencies and the private sector started to discover the new paradigm for the future of transportation that would use the current infrastructure, but also address the issues of safety, congestion, and environment. During the workshop in Dallas (Texas) in 1990, participants proposed the Intelligent Vehicle Highway Systems (IVHS) concept, which was later renamed to ITS [3]. The idea was that the current infrastructure could be connecting with advanced technology (in computing, sensors, information systems, and advanced mathematical methods).

The ITS concept became an integral part of the 1991 Intermodal Surface Transportation. Intelligent Vehicle Highway Society of America (later renamed Intelligent Transportation Society of America). The plan called for the integrated operation of the system using technology to bring together information about modes and current conditions.

ITS covers many areas that have been adjusted and renamed over the years, but the basic tenets of safety, mobility, and environment have remained. The management systems cover information, traffic (signal systems and tolling), designated Advanced Traffic Management Systems, and Advanced Vehicle Control Systems.

ITSs use Vehicle-to-Infrastructure (V2I) communications.

6.2.2. VANET

The term VANET appeared in 2004, than program chair of ACM conference gave a name “Vehicle ad hoc network (VANET)” to his workshop [19]. VANET is a variation of MANET (Mobile ad hoc network), with the emphasis being now the node is the vehicle [18]. The idea is that Ad hoc networks can be formed by cars in order to help overcome blind spots and avoid accidents. Mobile nodes (vehicles) have a vehicle module enabling vehicles to communicate over wireless Vehicle-to-Vehicle (V2V) channels (Fig. 2). Ad hoc networks do not need infrastructure connection in the process of forming a network. One vehicle node can connect to other nodes directly if the distance between the cars is enough to get a signal (less than so called communication distance). VANET is a spontaneous, self-organized, multi hop and high dynamic network [20]. Speed of vehicles is high and network topology is constantly changing.

Over the years, there have been considerable research and projects in this area, applying VANETs for a variety of applications, ranging from safety to navigation and law enforcement.

Modern vehicular networks tend to combine VANET function with ITS function. In this case, we can see that VANET projects have also fixed nodes on the road (Road station) which have their roots from ITS functionality (Fig. 2). These hybrid network systems use V2I communications to connect vehicle with road station. There are a number of researches in the area of V2I connectivity for VANET [20]. In [21], the authors propose a seamless communication with an opportunistic choice of a vehicular protocol between V2V and V2I.

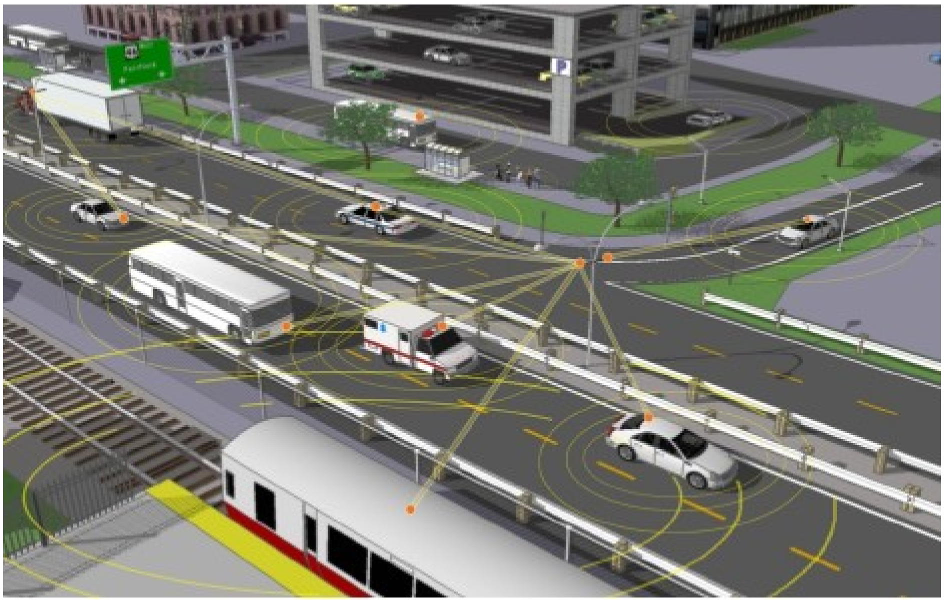


Fig. 2. VANET (V2V and V2I communications)

6.2.3. Communications for Vehicle networks

In fact, vehicle communication is a concept of M2M (Machine-to-Machine) communication, applying for vehicles.

The class of technologies named **M2M** is used for communication between devices. M2M is technology that allows *devices of the same type* to communicate between each other. *It is possible different way to connect devices*: M2M use special microchips embedded in the device and M2M protocols.

Due to this technology devices of the same type can communicate *without human participation*. M2M is used in the different fields: cellular communication, industrial automation, transportation, logistics, Smart Cities, Smart Grids. Thereby, devices can be machines, vehicles, phones or others.

M2M technology can be implemented for private goals as Smart devices, Smart Home, as well as has an industrial implementation in automation. The sensors send the data between each other and could capture some event. M2M systems use mostly wireless communication, but they can implement wired of hybrid connection.

However, modern M2M communication has expanded beyond a device-to-device connection and changed into a device networks.

Vehicular communications is an important part of Vehicular Networks. Vehicle networks aim at enhancing of the road safety and efficiency through intelligent transportation, which integrates communication between mobile and fixed nodes [7]. To this end, ITSs and VANETs use wireless and wired communications.

Communications between cars have a several well-established names:

- ✓ Car-to-Car (Car2Car, C2C),
- ✓ Vehicle-to-Vehicle (V2V).

The V2V communication based on different wireless technologies as was mentioned above. The most useful VC technology is Dedicated Short-Range Communications (DSRC) in USA and Wireless Access in Vehicle Environment (WAVE) in EU. The V2V enables to connect the vehicles between each other and it is a basic technology for vehicle networks. The V2V could identify potential dangerous situations and alert the drivers so that collision could be avoided.

A number of companies joined the Car-to-Car Communication Consortium for the consolidation of efforts in the work [22]. V2V is currently in active development by General Motors, which demonstrated the system in 2006 using Cadillac vehicles. Other automakers working on V2V include Toyota, BMW, Daimler, Honda, Audi, Volvo and the Car-to-Car communication consortium.

In April 2014 it was reported that U.S. regulators were close to approving V2V standards for the U.S. market, and that officials were planning for the V2V technology to become mandatory by 2017.

Communications of the car with the infrastructure referred to as

- ✓ Car-to-Infrastructure (C2I),
- ✓ Vehicle-to-Infrastructure (V2I) or Vehicle-to-Roadside (V2R).

The most used technology for V2I is the same with V2V (5.9 GHz DSRC and WAVE). V2I communication involves the wireless exchange data with highway infrastructure. The V2I communication enables real-time traffic information to enhance road mobility, information about road conditions and weather. V2I applications complement the V2V safety applications by addressing crash scenarios that the V2V program cannot address or that could be addressed more efficiently. The following is a list of V2I potential safety applications: control of the traffic lights to prevent congestions; speed control; traffic congestion notification; red light warning; reduced speed zone warning; weather notification; railroad crossing assistance.

Vehicle-to-vehicle and vehicle-to-infrastructure communications are considered as a key technology for safe and intelligent mobility in the future.

But V2V and V2I terms do not reflect the full range of VC. Therefore, in recent years we can hear the term **Vehicle-to-X (V2X)** or **Car-to-X (C2X) communication**. Under the "X" can refer to vehicles (V2V), infrastructure (V2I), server (V2S), pedestrian (V2P). V2X communication is considered in the latest researches like the relevant challenge for the next 5-10 years [23] [7]. A number of V2X research related to vulnerable road users (pedestrians and motorcycles) safety [24], [25], [26], [27], [28], [29], heavy vehicles, buses [30].

Recently, a set of wireless **VC Standards** have been developed:

- ✓ ***Dedicated Short-Range Communications (DSRC) Standard SAE J2735 (USA)*** is a pioneer VC Standard [31]. DSRC is a class of direct WPAN communication based on radio waves. In 1999 the 5.9 GHz band with bandwidth of 75 MHz and approximate range of 1000 m set aside for DSRC in the USA. And only in 2006 the first V2V research using DSRC was initiated in USA. Both vehicle and infrastructure nodes can use DSRC. The network should support both private data communications and public (mainly safety) communications but higher priority is given to public communications. Now this Standard is the most used vehicle communication technology.
- ✓ ***Wireless Access in Vehicle Environment (WAVE)*** [32]. WAVE is a Wi-Fi version for vehicles. WAVE is the European version of the USA DSRC Standard. It works on the DSRC band. WAVE relays on APP NET layers IEEE 1609, PSY IEEE 802.11p.

- ✓ ***Connection over cellular networks***. Not so long ago, vehicle communication over cellular networks was posed a problem, because of latency of 2G networks (GSM standard) and even 3G networks (UMTS standard) is significantly larger compared with DSRC. The factor of latency becomes particularly important for delay-sensitive vehicle applications. But the latency of cellular networks has been significant reduced in the transfer to 4G network (LTE-advanced in 3GPP standard, WiMAX) [33]. In the paper [34] is shown the way of using smartphones as WAVE devices for V2V and V2P communication.
- ✓ ***Hybrid communication protocols*** are a promising avenue of VC. The approach contributes to more seamless connectivity [21].

6.2.4. Overview of ITS, VANET projects

There are many ITS and VANETs based on V2V and V2I communications (V2X) were developing in the past [18]. Work on the vehicle systems usually organized like a separate projects. USA Department of Transport (Federal Highway Administration) has been a pioneer in large scale developing of Vehicle Networks [35]. The first historic projects are:

- AHS (Automated Highway System), (USA) [36];
- IVI (Intelligent Vehicle Initiative)/VII (Vehicle Infrastructure Integration), (USA) [37];
- CVI (Connected Vehicles Initiative), (USA) [38];
- CVSPP (The Connected Vehicle Safety Pilot Program) [39]/CVPDP (The Connected Vehicle Pilot Deployment Program) [40] (USA)

These USA projects have laid the foundation and terminology of further Vehicle Networks (ITS, VANET, cooperative vehicular systems structure) and Vehicular Communication (V2V, V2I, DSRC Standard).

Then European Union took the initiative to develop ITS:

- CVIS (Cooperative Vehicle-Infrastructure Systems), EU, 2010 [41];
- PRE-DRIVE (PREparation for DRIVing implementation and Evaluation of C-2-X Communication technology), EU, 2010 [42];
- SAFESPOT (Cooperative vehicles and road infrastructure for road safety), EU, 2010 [43];

- SIM-TD (Safe Intelligent Mobility - Testified), Germany, 2014 [23];
- COMeSafety (Communications for eSafety), 2009 and COMeSafety2, 2014, EU [44];
- AdaptiVe (Automated Driving Applications & Technologies for Intelligent Vehicles), EU, 2017 [45].
- C-ITS (Cooperative Intelligent Transport Systems), 2016-2020, Horizon 2020, EU [46], [47].

Let us describe the most interesting projects.

6.2.4.1. *Automated Highway System (AHS) (USA)*

In 1992 the U.S. Department of Transport (DOT) started the AHS Program. A basic concept was that vehicle sensors would communicate with the road, to enable “hands-off” and “feet-off” driving. Dedicated road lanes would be constructed for this purpose. These lanes would be contained magnetic nails. The vehicle sensors would recognize dedicated lane and guide the vehicle down that lane. The benefits of AHS would theoretically be derived from decreasing the amount of driver error; increasing the capacity of the highway; facilitating reduced fuel consumption and tailpipe emissions; and providing more efficient commercial and transit operations. The research culminated in a 1997 demonstration conducted on I-15 in San Diego, California.

However, the idea of AHS about dedicated lanes posed a problem of fitting these lanes on the roads and other problem was high-cost construction of these lanes. That’s why the project has not been implemented.

6.2.4.2. *Intelligent Vehicle Initiative (IVI) and Vehicle Infrastructure Integration (IVI) (USA)*

Then DOT has started the Intelligent Vehicle Initiative (IVI) in 1997. The IVI aimed at estimation of driver acceptance and facilitating deployment of collision avoidance systems. The IVI included development of vehicle and infrastructure cooperative assistance applications.

The Vehicle Infrastructure Integration (VII) Initiative brought together the results of the IVI. VII used both V2V and V2I connection to send information between vehicles and to the infrastructure (10th Intelligent Transportation Systems World Congress in Madrid, Spain, in

November 2003). In 2006, the DOT entered into a cooperative with five automotive equipment manufacturers to investigate DSRC and GPS relative positioning.

The main issue of VII system is that it requires road-side equipment (RSE) and vehicle equipment (OBE). The other important issue is that message protocols needed to be established that allowed time-constrained communications between OBEs and RSEs.

6.2.4.3. CVIS Project (EU)

The Cooperative Vehicle Infrastructure Systems (CVIS) project was launched by ERTICO-ITS Europe Partnership [5] in 2006. The project was finished in 2010.

The ERTICO Partnership focuses on cooperation of relevant stakeholders in order to develop ITS in Europe. The Partnership includes around 100 companies and institution involved ITS: mobile network operators (Ericson, Orange, TIM), vehicle manufacturers (Volvo, Ford, Toyota, BMW, FIAT), European research institutions, traffic and transport industry (Xerox, Siemens, Michelin), etc.

There are three subsystems in the CVIS: vehicle system, roadside system and central system (Fig. 3) [7].

Vehicle subsystem provides information from the car`s sensors. The CVIS project designed special sensor card connected to the car PC. This card provides location data of the vehicle. CVIS gets coordinates both from GPS sensor and sensors of the navigation system (gyroscope and accelerometers) using CAN-bus interface to the vehicle.

CVIS project proposes to build into the car on-board PC (computation module). On this PC installed both software for communication with infrastructure and connection with car equipment. CVIS has distributed client-server architecture. There are two parts: one named the mobile router (server) and second named mobile host (client).

Mobile router is a server part. It performs all networking operations and acting as the interface to the car processors and sensors. The CVIS project developed a special sensor card. The card provides GPS data for accurate time and position, an inertial sensor package with gyroscope and accelerometers, and an interface to the vehicle CAN-bus. Special car`s sensors cards connected to the mobile router. Mobile router combines data from all these cards. It is a critical real-time application, which resolve task of real-time acquisition of location and time synchronization.

Mobile host is a software application, which provides computing algorithms for vehicle communication and user interface.

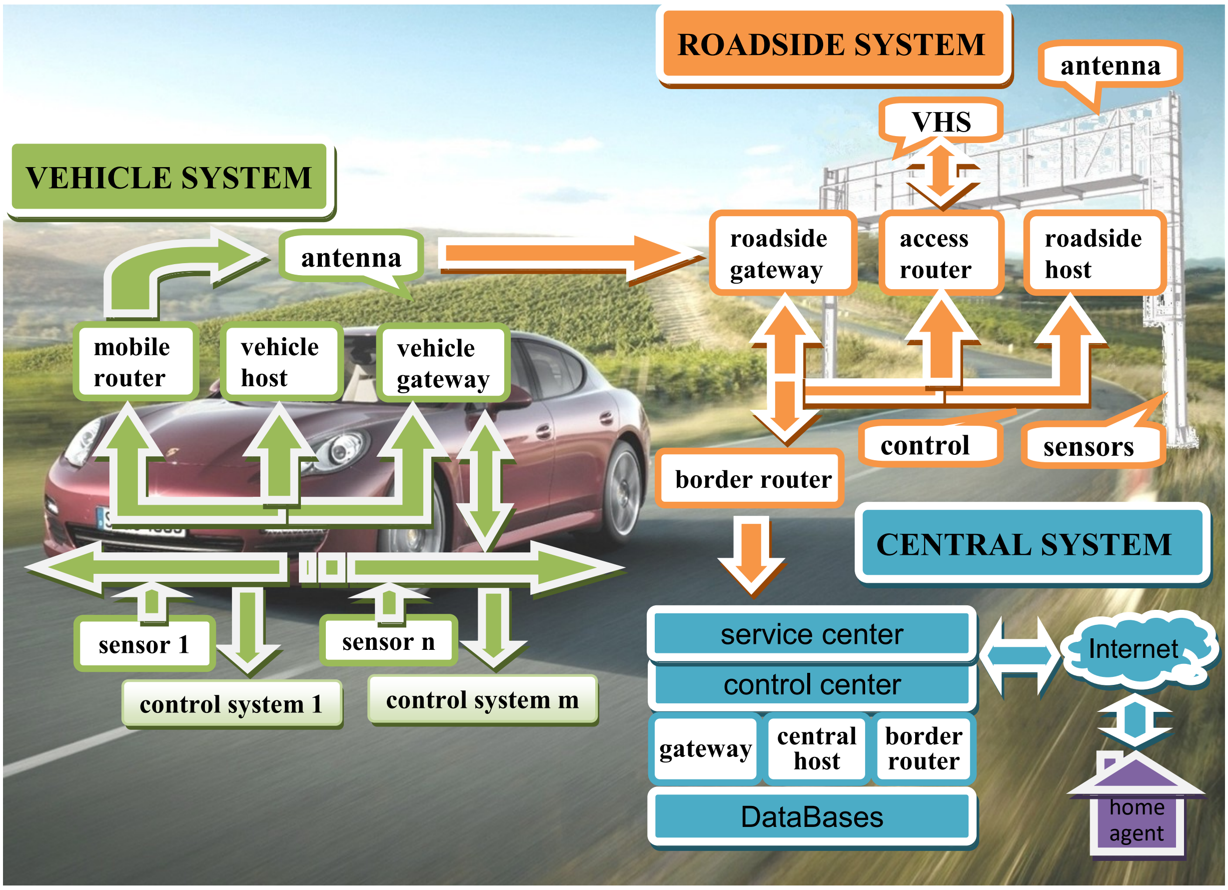


Fig. 3. CVIS project

Roadside system includes road sensors, control mechanisms, antenna. It connects to the central system from Internet by IPV6 protocol. Central system also connected with Internet to provide user information and home client apps functionality. It is seems to be IoT, but we do not find word IoT in the CVIS description. This suggests that CVIS is not fully IoT based system, but it has simile structure to the communication based on IPv6.

Advantage of the CVIS, at first, is open standards-based communication and positioning technologies. Second, the platform is suitable for both in-vehicle and RSU. Third, it uses infrastructure information (C2I). Also it has a continuous real-time IP connection both between the cars and infrastructure C2C, C2I (V2V, V2I). CVIS provides sustainable real-time road map. It has a distribute client server architecture. But other project COM2REACT also uses client server architecture.

6.2.4.4. V2X from "Safe Intelligent Mobility- Testfield Germany" (SIM-TD) (EU)

SIM-TD (Safe Intelligent Mobility - Testified Germany) is a German project using Car-to-X communication. Goal of this project was to test Car-to-X application in real large-scale deployment. In SIM-TD research institutes, government, automotive corporation (Mercedes-Benz, Audi, BMW, Volkswagen, General Motors and Ford) and telecommunication domain were working to deploy project in metropolitan field trial in the Frankfurt Rhine-Main [23].

System functionality includes warning message about emergency on a road and recommendation about an alternative route, emergency button for the driver. In addition, the system of "Car-to-X" will be able to warn about what a number of rebuilt, the presence of queues at the petrol station, border, typical of the West toll roads; will be able to assess in advance the cycle of the traffic light and offer the best rate to get the green signal, or to reduce speed, if soon will turn red; to allow the drivers to exchange opinions about the quality of the roadway.

SIM-TD composed of two parts (Fig. 4): vehicle domain and infrastructure domain. The vehicles are able to communicate each other using short range communication based on IEEE 802.11p (C2C communication). And the vehicles have ITS vehicle station - IVSs to connect car with infrastructure, also it has IP based UMTS communication hardware.

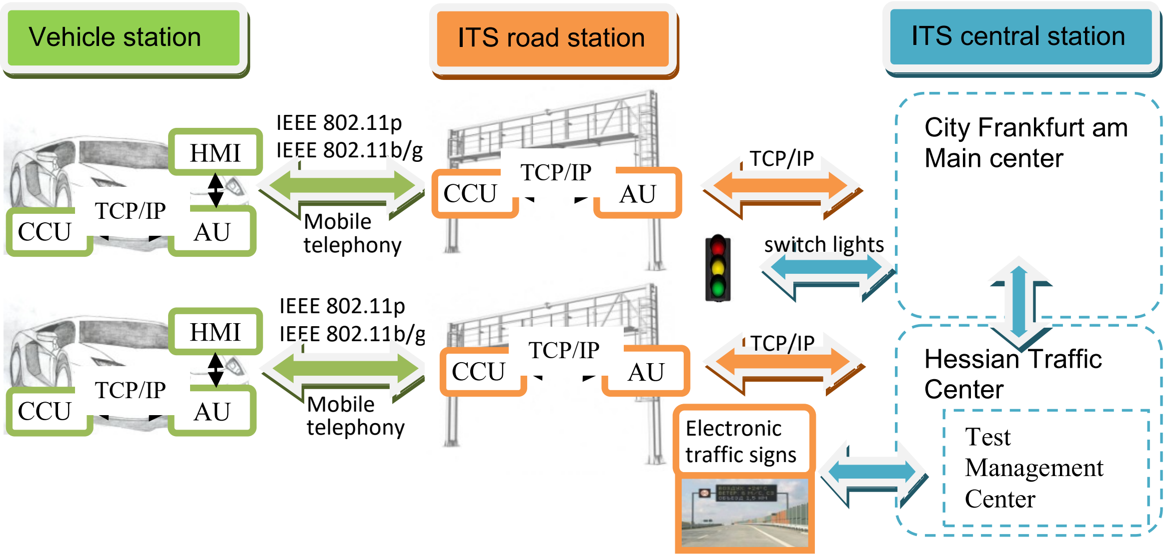


Fig. 4. SIM-TD system architecture

Moreover, SIM-TD includes about 100 ITS roadside stations (IRSs), which integrated in the V2V network with protocol IEEE 802.11p and connected with infrastructure domain using WLAN based on IEEE 802.11b/g. The IRS connected with the traffic lights switches. The IRSs are able to evaluate the state of the traffic lights in real time to reduce overall stop times at traffic lights [48].

Also the system has ITS central stations (ICSs). Information exchange between vehicles and test centre, instruct the drivers and log information integrated in the system by using the UMTS link [48].

Messages between IVSs, IRSs and ICSs are described in ASN.1 format and transport level is Packed Encoding Rules (PER). The connectivity of IRSs to traffic light switches based on OTS-2 standard. Data exchange between ICSs based on xml-oriented standard Datex-II v. 2.0.

ITS central station (ICSs) gets information from IVSs. ITS already has some information about traffic situation received from stationary equipment (such as detector loops in the lanes or some key points), but this information is not enough for accurately assess of the traffic situation. IVS information allows obtaining highly detailed traffic situation at every moment. It is performed by complex fusion of all traffic and road data. An assessment of the traffic situation generates once a minute. Vehicle (IVS) may request these assessments from the IRSs database for different calculations (routing, lost time calculation, congestions, alternative routes in case of traffic jams etc.).

The first cars equipped SIM-TD system with this safety system was Mercedes-Benz.

6.2.4.5. *Mercedes Car-to-X*

In-vehicle Mercedes PreSafe system is available in the Mercedes cars (

Fig. 5).

Also it is noteworthy that first versions of cars with **Mercedes Car-to-X** appeared by the end of 2013. However, the introduction of this system poses some additional challenges. Since the main advantage of Car-to-X - alerts in real time - it requires specific equipment, allowing drivers to be online, so the cars must be fitted with optional multimedia system for Mercedes-Benz Command Online with additional service Drive Kit Plus connected Smartphone installed Digital DriveStyle.

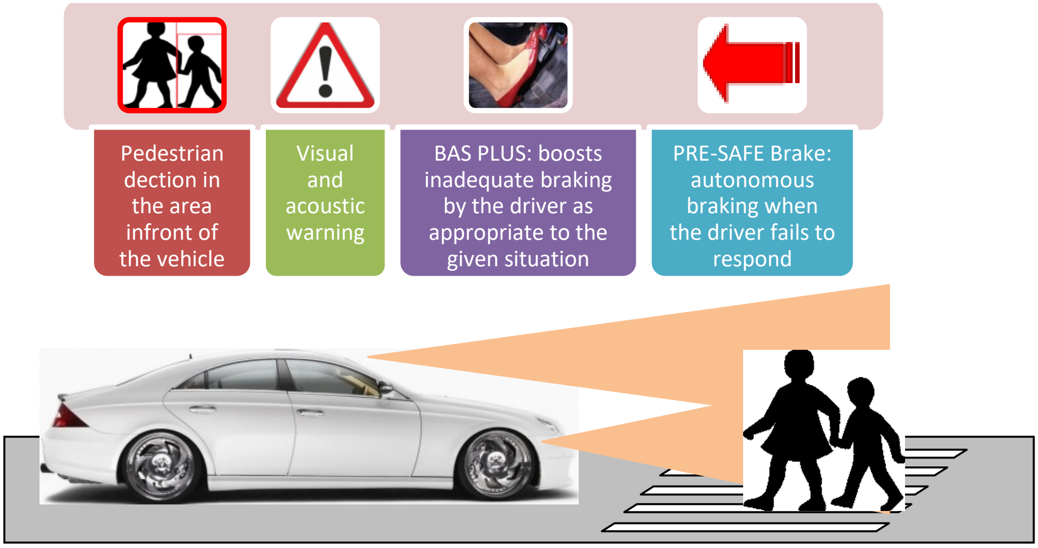


Fig. 5. Mercedes Presafe system

To implement a wireless connection to the vehicle is set to the number of structural elements antenna, receiver, transmitter, control unit, which can be combined into a single WLAN module. As the module can be used the usual Smartphone with appropriate software and synchronized with the car.

The antenna module provides a wireless connection. The transmitter and receiver respectively receive and transmit information. The main job is done by the control unit. It handles incoming internal (from the car) and external (from the network) signals and converts them into control output signals, which, in turn, transmitted to your car audio system and information display. In case of an emergency communication system can affect the controls of the car, preventing an accident.

In the C2C system there are several ways to alert the driver: sound signal and the color strip on the instrument panel that changes color depending on the degree of risk (Ford, Mercedes-Benz), beep and a warning sign on the center console (General Motors, Toyota), dashboard (Honda, Hyundai, Nissan, Volkswagen). Some manufacturers in addition to visual and audible alarms offer to use the vibration of the driver's seat backrest (vibrates the party, which is in danger).

6.2.4.6. Connected Vehicles Initiative (CVI) (USA)

The last DOT Initiative, the Connected Vehicles Program also aimed to investigate the possibility of using DSRC VC for transportation. Vehicle sensors are limited in terms of awareness distance. But wireless technologies are able to provide wide coverage. The program aimed at the development of V2V and V2I safety applications and estimation of these apps at safety enhances. Connected Vehicles Program is included in the ITS strategic plan for 2015-2019 [38].

6.2.4.7. The Connected Vehicle Safety Pilot Program (CVSPP) and the Connected Vehicle Pilot Deployment Program (CVPDP) (USA)

The *Connected Vehicle Safety Pilot* is other DOT project. The Pilot program aimed to test V2X safety applications using DSRC on real field conditions with warning devices, other safety systems and DSRC devices. The project relays on messages exchange between vehicles and infrastructure. Vehicle messages contain vehicle size, position, speed, heading, acceleration, brake status, steering angle, wiper status, turn signal status etc. The data acquisition was provided from light vehicles, and since 2014 it has been extended for the trucks.

There were two main subsystems in the Connected Vehicle Safety Pilot:

Safety Pilot Driver Clinics: The driver survey was provided in USA in 2011-2012 on the topic of acceptance of the V2V technology (wireless communication and race track).

Safety Pilot Model Deployment: The experiment aimed to estimate the effectiveness of V2V communication for safety application. The data acquisition was provided from light vehicles and trucks. The safety system was built on vehicle and awareness devices using DSRC communication.

The *Safety Pilot Model Deployment* is also tested V2I applications: traffic signal timing, pedestrian traffic, priority for emergency vehicles.

Then the *Connected Vehicle Pilot Deployment Program* was started in 2016 and now the program is under development [40]. It has three on-going projects: New York City DOT Pilot (NYCDOT Pilot), Tampa-Hillsborough Expressway Authority Pilot and Wyoming DOT Pilot. The Program is aimed to deploy and test multiple connection vehicle applications in the real traffic conditions using mobile and roadside technologies.

It has a set of V2V safety applications:

- ✓ Forward Crash Warning (FCW),

- ✓ Emergency Electronics Brake Lights (EEBL),
- ✓ Blind Spot Warning (BSW),
- ✓ Lane Change Warning/Assist (LCA),
- ✓ Intersection Movement Assist (IMA),
- ✓ Vehicle Turning Right in Front of Bus Warning.

CVPDP includes V2I applications:

- ✓ Intelligent Traffic Signal System (I-SIGCVDATA),
- ✓ Emergency Communications and Evacuation Information,
- ✓ Speed Compliance,
- ✓ Curve Speed Compliance,
- ✓ Speed Compliance/Work Zone,
- ✓ Red Light Violation Warning,
- ✓ Oversize Vehicle Compliance.

Moreover, it has V2P applications:

- ✓ Pedestrian in Signalized Crosswalk,
- ✓ Mobile Accessible Pedestrian Signal System (PED-SIG).

CVPDP is a largest vehicle network deployment to date: 500 vehicles, 1250 buses, 400 trucks, 5800 taxi are equipped with vehicle stations using DSRC, so called Aftermarket Safety Device (ASD). 310 RSU at signalized intersections, 8 RSUs along the higher-speed road at the locations such as short-radius curves or a minimum bridge clearance and 36 RSUs at other strategic locations enable V2I technology. Moreover, CVPDP also aimed at pedestrian safety: 11 cars with pedestrian Detection Systems (PED) for in-vehicle pedestrian warning and 100 VRU devices for pedestrians and cyclists with Mobile Accessible Pedestrian Signal System (PED-SIG).

6.2.4.8. Cooperative-ITS projects (C-ITS) (EU)

Cooperative Intelligent Transport System (C-ITS) is a European version of vehicle network system, which has been standardized by European Telecommunications Standards Institute (ETSI) EC ITS and European Committee for Standardization (CEN) TC278 WG16 [49]. C-ITS is a transport subset of ITS, which allows vehicles to communicate with other vehicles, infrastructure and other users. It will bring benefits of transport efficiency and increased safety. C-ITS system combines ITS functions with VANET, and uses both V2V and V2I communication. C-ITS can provide the increased quality and reliability of information about vehicle location vehicle and road environment.

The directions of C-ITS research:

- C-ITS services integration for urban and public transport;
- The provision of information from in-vehicle systems and DAS, integrating V2V, V2I and multiple vehicle systems.
- Research in widely accepted data acquisition.
- The increase in vehicle automation level;
- The development of C-ITS trust model and secure protocols;
- The interoperability in data management;
- The development of national and regional ITS deployment projects in accordance with C-ITS framework and standards in order to avoid fragmentation in the deployment.
- International cooperation to foster C-ITS deployment.
- Progress in on-going C-ITS standard definition for vehicle communications.
- Generation of massive quantities of traffic information through the different channels.

Many on-going projects fall under the theme C-ITS: C-Roads, C-Mobile, SoLC-ITS, CITRUS, InterCor, CODECS, BASIC [47].

6.2.5. Comparative analysis of the existing ITSs and VANETs

Project name	Year	Type of communications	Technology for communication	Required interfaces, computer powers inside a car/ infrastructure /pedestrian	Required in-vehicle sensors (detecting parameters)
Automated Highway System (AHS)	1992	V2R (Vehicle to Road)	Wireless: dedicated lanes (with magnetic nails)	Vehicle sensor to recognize dedicated lanes	Velocity, direction.
Intelligent Vehicle Initiative (IVI)	1997	V2I	Wireless: DSRC	DSRC-receiver	
CVIS	2006 – 2010	V2X, cellular	Wired: CAN bus. Wireless: WAVE, GSM/UMTS.	on-board PC, CAN interface, car sensors microchip, WAVE (DSRC) transceiver, GPRS transceiver, UMTS transceiver	Speed sensor (velocity), front and rear cameras (video), GPS receiver (coordinates, direction), Inertial Navigation module, Road mapping, Temperature sensor (temp), airbag status, parking sensors (distance to obstacle).
COM2REACT	2006 – 2010	C2X	Wireless WAVE	CAN gateway, WAVE receiver	GPS, Camera, Ultrasound sensor.
SIM-TD	2008 – 2014	V2X, cellular	Wired: CAN bus. Wireless: WAVE, UMTS.	On-board PC with Windows XP extended, CAN interface, ITS Vehicle Station (IVS), ITS Road Station (IRS), UMTS transceiver, ITS Central Station (ICS) – City Datacenter.	Speed sensor (velocity), DGPS receiver (coordinates, direction), and others sensors able from CAN,WLAN interfaces.
Mercedes Car-2-X	2013	V2X	In-vehicle CAN bus Wireless WAVE receiver	antenna, receiver, transmitter, control unit, CAN interface.	abrupt change of direction of movement, the speed of individual wheels, sharp pressing the brake pedal.
Connected Vehicles Initiative (CVI)	2015 – 2019	V2V, V2I	Wireless: DSRC Cellular, Wi-Fi, Satellite	DSRC-receiver, Road Side Unit (RSU), cellular, Wi-Fi, satellite receivers	CV applications
Connected Vehicle Pilot	2014- to date	V2X (V2V, V2I, V2P)	Wireless DSRC	DSRC-receiver, Road Side Unit	CVPP Applications, Aftermarket Safety Device

Deployment Program (CVPDP)			Cellular, Wi-Fi, Satellite	(RSU), VRU device	(ASD), PED Detection System.
C-ITS projects	2014 - to date	V2V, V2I	Wireless: WAVE, Cellular, Wi-Fi.	DSRC-receiver, Road Side Unit (RSU),	C-ITS applications

Table 1. Classification of the Vehicle network projects

6.2.6. Advantages, disadvantages and future development of DASs, ITSs and VANETs

The vehicle systems (VANET and ITS) can be used in various fields, including safety and traffic management. In the future vehicle systems such as ADAS/CoDAS and vehicle networks will be the basis for high-automated and autonomous vehicles.

Ensuring safety is the primary function of VANET. The idea is that if the vehicle has obtained information and vehicle network logic has detected a potential danger, system warns relevant road users via V2V communication.

VANETs provide safety in the following areas:

- assistance during the passage of the intersection;
- help when turning left;
- safe separation from oncoming vehicle;
- warning when leaving for highway;
- detection of obstacles on the road;
- information about the traffic accident;
- autonomous emergency braking system;
- warning front and rear collision (e-stop signal);
- warning about lane change;
- warning about the bad weather conditions;
- information on the road signs;
- vehicle-vehicle, vehicle-VRU collision avoidance systems.

A number of these applications have already been implemented on modern cars as ADAS functionality using in-vehicle sensors (video cameras, radar, Lidar). For instance, emergency braking assistance system, assistance when change the lane, recognition of traffic signs. But the technical capabilities of cooperative DAS using Vehicle Communication is much wider, none standalone systems, which cannot see around corners. Thereby, applications such as cooperative active and passive driver assistance systems, vehicle and VRU collision avoidance systems, cooperative assistance in passing intersections, turn left, cooperation and collaboration between manually driven, high-automated and autonomous vehicles are under the active development.

The potential dangers can be recognized on the basis of the evaluation of the movement of the car. Even the driver danger behavior can be detected by in-vehicle camera (drowsiness state, distraction) and other in-vehicle sensors (the speed of individual wheels, sharp pressing the brake pedal), as well as by infrastructure sensors (infrastructure camera can detect abrupt change of direction of movement [50].

ITSs are widely used in traffic management. ITS is aimed to prevent traffic congestion, as well as the adaptation to specific weather conditions. The main ITS applications are:

- Regulation of the traffic flow speed by control the traffic lights in order to avoid both recurring and non-recurring (due to incidents or some events) traffic congestions [51]. Providing movement in the "green wave".
- Vehicles routing, mapping, estimation of delay [52] and the choice of the optimal route according to different criteria (time, fuel, fees).
- Managing of public transport routing and transfers.
- Warning about "the tube", weather conditions, roadworks.

A number of applications are widely used in many counties, such as electronic payments, whereas others are under the development. Along with the traffic control, ITS also allows to control car routes, which must be demanded by the Supervisory authorities (police, security service). The communication system may be used to obtain various kinds of content, not directly related to driving. Wireless Internet allows to search for information, download files, send (receive) e-mail messages to use electronic games. Thereby, keeps track of all routes and other user information posed the problem of privacy.

If the development of communication systems for vehicles is quite active, the implementation of these systems has a number of outstanding issues (Table 2). The main problem is the low level of the distribution system, due to relatively high rates WLAN module.

For effective use of the V2V, at least 10-15% of vehicles must be equipped with DSRC equipment, and it is very far away. At present, WAVE/DSRS still is not widespread [53]. Moreover, existing WAVE/DSRC solutions based on Carrier Sense Multiple Access (CSMA) and Peer Aware Communication (PAC) do not support Quality of Service (QoS), which is critical for suitability of vehicle communication for safety emergency applications [53].

Another problem is the relatively low degree of system reliability in determining risk. If the driver receives a warning from the system, it does not mean that there are no dangers. Even if all cars and motorcycles will be equipped with V2V, remain pedestrians, cyclists, where system is absent. However, cyclists and pedestrians are the most vulnerable road users (VRU). And only latest on-going project try to take into account VRU, but still VRU has to have additional DSRC-devices.

Also, vehicle network can simply overwhelm the driver of various kinds of information, from which not all are needed for driving. This, ultimately, will constantly distract the driver from his primary occupation of driving.

Another issue, associated with the privacy and security of information in the wireless network. Vehicle systems enable new attack vectors for hackers and emerge issue of privacy during the driver`s data processing, companies/governments can use it in selfish purposes.

Issues	**ADAS**	**VANET**	**ITS**	**cooperative VANET/ITS V2X**
System can improve significantly safety	Yes only in LOS conditions	Yes (both LOS and NLOS conditions)	Yes only in some specific conditions (bad weather conditions, road repair, events)	Yes
System can manage traffic flow and minimize traffic congestions	No	No	Yes	Yes
System can estimate routing delay	No	No	Yes	Yes
System can provide routing, mapping	Yes	No	Yes	Yes
System requires an embedded vehicle module or sensors in the car which is not available in the common car models	Yes	Yes	Yes	Yes
System requires an infrastructure module (road side unit),which is not widespread	No	No	Yes	Yes

system tends to be expensive for the drivers	Yes	Yes	No	No
System requires expensive equipment for road infrastructure and Data centers	No	No	Yes	Yes
system has a low reliability in determining dangers.	Yes (in NLOS conditions)	Yes	Yes	No
System is not interconnected with others	Yes	Yes	Yes	Yes (No for on-going C-ITS research)
system has no an access for drivers via Internet on private gadgets.	Yes	Yes	Yes/No	Yes/No
Driver cannot use his gadgets and sensors like a data source in the system	Yes	Yes	Yes	Yes

Table 2. Outstanding issues of systems providing road safety

The modern on-going research program C-ITS, sponsored by European committee and Transport Research and Innovation Monitoring and Information System (TRIMIS) try to fix these issues. For example, C-ITS system pays a lot of attention to privacy and security aspects and system interoperability [54].

Moreover, there is a trend towards connected systems. On-going transport vehicle researches Connected Vehicles (USA) and Cooperative-ITS (EU) searching for ways to fuse ITS, VANET and DAS functions and use all their benefits. It can improve significantly reliability and efficiency of safety applications.

Another important issue of existing vehicle networks is that the vehicle communication was grown from machine-to-machine communications (M2M). But M2M concept itself has evolved over the last few years and new IoT concept was formed. Therefore, up-to-date transport solutions need to be further developed.

6.3. Modern Trends of Vehicle Systems

6.3.1. From M2M to IoT/IoE and IoV

The recent global paradigm shift in technology known as the Internet of Things (IoT) will happen in the next few years [55]. The IoT concept originates from the idea of machine-to-machine (M2M) communication. Since M2M came out of the scope of communications between devices of the same type, it has been further developed into a broader and more promising concept of communication between different types of devices, so called IoT [56].

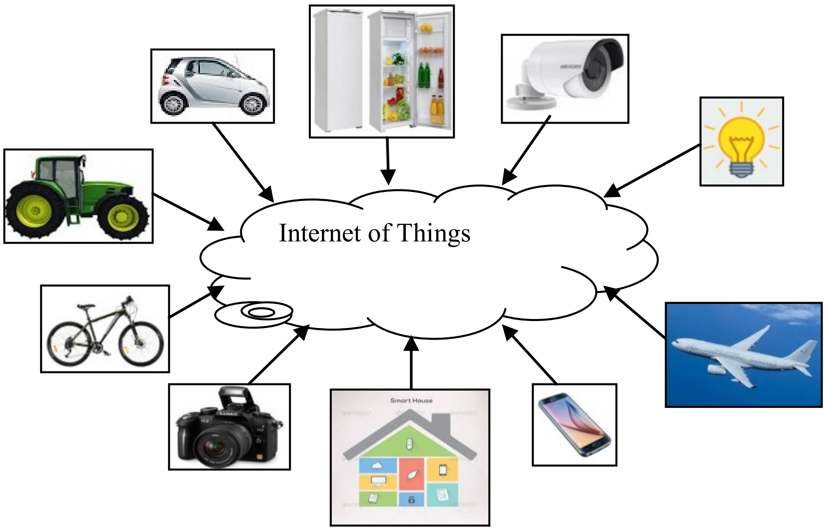


Fig. 6. Vehicles in IoT concepts

The term "Internet of Things" appeared in 1999 by British visionary Kevin Ashton [57].

The Internet-of-Things (IoT) is the network of connected sensors, devices, gadgets via IP (Internet) (Fig. 6) [55]. ***The idea of IoT is to offer advanced connectivity*** of devices, systems, and services that goes beyond machine-to-machine communications (M2M) and ***covers a variety of protocols, domains, and applications.***

In the terms of IoT, sensors, devices and gadgets can be "things" in IoT. "Things" can refer to a wide variety of devices, such as temperature and pressure sensors in industry automation; light, motion sensors or fire detector in home automation; camera, radar of Lidar sensors in transport; heart monitoring implants in medicine; biochip transponders on animal farms; electric clams in coastal waters. These devices collect data via various communication technologies and then manage the data flows between other devices. Connectivity enables exchanging data with the servers, other connected devices and users. Each "thing" is identified by its embedded IP addressing (IPv6) and it is able to interoperate within other connected devices via the existing Internet infrastructure. IoT is a kind of global Internet connected automation.

The interconnection of these embedded devices (including smart objects) enables the automation in nearly all fields, while also enabling advanced applications like a Smart Grids [55]. Current applications include smart thermo systems, smart washer/dryers systems for plants, smart houses, smart city applications, smart trucks which utilize wireless communications for remote monitoring and control.

Sometimes, terms M2M and IoT are used together and for the same systems and in the same significance. It is happened because of concepts are new and now don`t exist exactly correct determine for this terminology.

The difference between IoT and M2M:

1. Many experts suppose that IoT has their roots in M2M. And nowadays, M2M became a part of more global concept IoT and its future is considered as development as an integral part of IoT [Cisco, IBM] [56].

2. IoT connects devices of the different types. M2M connect usually devices of the same type.

3. Communication between M2M devices can be organized any way mostly wireless system. Communication for IoT – IoT can support different type of protocols, but in the end edges IoT uses the connection through the Internet by IP address and usually IP-stack. Any “IP-enable” devices, which support IP and IP/TCP stack, can be directly connected to the IoT system.

4. The processes of data acquisition and data processing are usually separated in IoT, and in M2M applications it can be indivisible.

5. IoT enables “things” to connect via Internet with intelligent computing platforms and, in the end. with human users, which allows human to interact with things and information. M2M is more aimed on devices connectivity and enables them to communicate without human participation [56].

Cisco is a one of the leader company in the field of IoT solutions. Cisco expects the rapid expansion of IoT technology. Near 50 billions of devices will be connected to the IoT network to the 2020 in accordance with prognosis of Cisco experts. Number of devices connected to the IoT was over 12.5 milliards in 2011 [55].

Cisco presented new paradigm of the future developing of the high IT technologies – **Internet of Everything (IoE)** concept on the forum in Chicago and Milan in January, 2015 [58]. The new IoE Platform and IoE Services were presented by Cisco. IoE (Internet of Everything) is an extension for the IoT concept (and transport systems like a part of IoT).

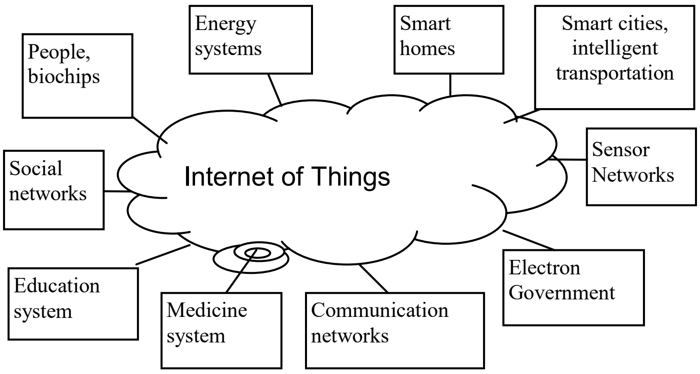


Fig. 7. Intelligent transportation and Vehicle networks in IoE concepts

IoE – is a convergence of different data flows, platforms and systems from different spheres of life (Fig. 7):

- manufacturing,
- energy,
- transportation,
- government,
- public safety,
- healthcare,
- education,
- financial services;

IoE interconnects people, data, things and process.

IoE in the opinion of the Cisco and leader company experts is a new step of the civilization progress [58]**.** The company ZebraTechnologies (NASDAQ: ZBRA) [59], a leader in solutions for the data collection and analysis in real time, published the results of a study of trends in transport and logistics. 96% of respondents said the Internet of things strategically important activity of their companies in the field of high technologies in the next 10 years [60].

It is expected, that the extremely huge amount of devices, sensors, machines will be connected to the IoT/IoE network. Hence, that is required an extremely large address space. A well known fact, that IPv4 is not large enough to support the future requirements of IoT. The global adoption of Internet Protocol Version 6 (IPv6) is actual problem for IoT, it would make it possible the direct addressing in IoT [61], [62], [63].

IoT/IoE is the concept of the future transportation as well. IoT is a trend of the development of ITS systems for the next years [56]. Connected Vehicles will establish, so named, Internet-of-Vehicles [53], [64], [65], [66], [67]. Vehicle communication technologies will be based on IoT in the future [53], [68], [69].

V2X communication has to be adopted for IoT. The protocols for IoV are:

- ✓ **6LoWPAN** (Low Power WPAN) is IPv6 stack for Wireless Personal Area Network (WPAN) IEEE 802.15.4 (PSY, MAC layer) [70].
- ✓ **MQTT (**Message Queuing Telemetry Transport)– is APP layer IoT protocol. It works both over TCP/IP and UDP transport (so called, MQTT-SN). MQTT can use TLS/TSS for security. MQTT based on publish-subscribe model, where all messages come through MQTT Broker. MQTT supports 3 QoS levels: MQTT0, MQTT1 and MQTT2 [71].
- ✓ **CoAP** (Constrained Application Protocol) [72] is APP level protocol. It is web transfer protocol for IoT (HTTP adapted for IoT). CoAP is a binary protocol (not text). CoAP enables the easy way to transfer into HTTP. CoAP works over UDP transport. This protocol provides message transfer between points, but also it supports broadcast mode. CoAP messages can be confirmable/non-confirmable. CoAP based on response/request model and it has architecture same with REST (methods get, put, post, delete). This protocol supports DTLS Datagram Transport Layer Security (TLS version for UDP transport).
- ✓ **HTTP/2** [73] – APP layer protocol. It is a low power and low volume version of HTTP 1.1. The protocol works over TCP transport. Thereby it can use classic TLS/TSS encryption. HTTP/2 based on response/request model.
- ✓ **ZigBee** – is representation, NET layer protocol [74]. It works over WPAN IEEE 802.15.4 (PSY, MAC layer) [70], as well as up Wi-Fi, Ethernet. ZigBee is not a common vehicle communication technology, but it has a lot of application for vehicles. This specification based on wireless personal area network (WPAN) as Bluetooth. But ZigBee has a set of important enhances. The protocol supports different network topologies including *mesh*, making it appropriate for short distance Vehicle ad hog network (VANET) communication [75], as well as ITS V2M communication with roadside devices [76]. ZigBee is a kind of Bluetooth

for mesh networks. ZigBee has low energy consumption. It works on 2.4 GHz worldwide (and local Standards 784 MHz in China, 868 MHz in Europe and 915 MHz in the USA and Australia). ZigBee transmission distances are 10–100 meters for two devices, but in the mesh networks the transmission distance can be much more. ZigBee protocol is often used for smart solutions (smart houses, smart energy and industrial apps).

- ✓ **Bluetooth LE (low energy)** [68] is a protocol for wireless personal area network (WPAN) IEEE 802.15.4 (PSY, MAC layer) [70]. Bluetooth supports IPv6 through Bluetooth(R) or 6LoWPAN; both TCP and UDP transport layer and able to work with MQTT and CoAP on APP layer.
- ✓ **WiFi-Direct** [77]**.**
- ✓ **LTE-Direct** [53]**.**

Many researches were provided in the different aspects to enable the future IoT transport applications. The analysis of vehicle Bluetooth interfaces (build-in/external infotainment systems and OBD-2 port dongles) for mobile IoT devices is presented in [68]. The authors note probable security issues: the Bluetooth IoT connection can be attack vector for hackers. The analysis of suitability of D2D and V2V communication for IoV is provided in [53]. As well as in-vehicle communication has to be adopted for IoT [69]. In [69], the authors proposed the in-vehicle power line communication and their view of how in-vehicle system can be merged into IoT. In the paper [64] is proposed a new road side unit (RSU) architecture (so called, RSU cloud), which consists of traditional WAVE based RSU and specialized RSU microdatacenter (resource manager (RSU CRM), OpenFlow controller and RSU Cloud controller). RSU cloud works as a getaway in order to provide interconnection with IoV, as well as provide easier data migration, reconfiguration, minimize delays and able to provide QoS, which is critically important for real-time safety application.

IoV, as such, is under researching and developing. The large-scale implementation projects, such as for DSRC-based ITS and VANETs, are not yet provided. In 2014 European Committee launched Smart Cities Initiative [78] and IoV can be considered like a part of the future smart connectivity. Also nowadays, we can find some commercial solutions on the market for the future IoV. For instance, the IoV solution from Huawei [79]. As well as, we can find some systems for research experiments. In the paper [66] the multi-car positioning and communication system using IoV is proposed. This system uses 3G+ cellular network, GPS, Smartphone/tablet with Android for end user interaction. In [65], the authors propose the system for safe driving based on IoV. This system use analysis of multi-aspects information, such as driver behavior and habits analysis, fatigue driving detection (based on driver`s eyes detection from in-vehicle camera), dangerous from other cars. In [80] the authors propose IoV traffic management solution. In [67] the authors consider the urban IoT architecture with SOA approach, including protocols, link layer technologies, getaways and DBMS and demonstrate the experimental architecture of Padova Smart City.

Besides the plethora of new application areas for IoT, it will aggregate very quickly the huge amounts of different data, thereby increasing the need to better index, store and process the data. Great computing potential of IoT and IoE concept based on Cloud and Fog computing, For IoT services cloud computing determines a concept structure of HW and SW service organization.

6.3.2. Cloud/Fog Computing Technology and Vehicle Systems

In fact, IoT/IoE services are hosted in the powerful Cloud or Fog Datacenters. Usually these services are provided to all end users by IoT Cloud Providers (ICPs). It gives us all advantages of Fog/Cloud computing paradigm.

Cloud/Fog Computing – are technologies, which provide remote distributed access to the resources (infrastructure, software, servers, platforms) via wide high speed connection channel / high speed internet.

Cloud computing has absorbed the experience of computer systems and network technologies accumulated over the years (Fig. 8). As a result, Cloud computing technology was formed.

The basis technologies for Cloud computing are:

- Distributed computing;
- Virtualization (level computer, operation system, machine VM)

VM Ware, Virtual Box, Microsoft Hyper-V

- Parallelization;
- SOA – Service-Oriented Architecture
- GRID networks;
- Intranet (IEEE 802)

- Web 2.0
- High speed internet/network connection (wide fibre channel, Wi-Fi, 4G+);
- Parallel programming;
- Cross-platform programming.

The foundation stones of the Cloud computing are *Virtualization, Parallelization* and *Distributed computing*. However, these features are usually associated with VPN services as well. But Cloud DC is not only VPN service like it may seem. Cloud computing is more powerful, super powerful. It provides distributed computation on different instances and in different data centers even remote geographically from each other and from the end users. Cloud DC can involve additional computation power (instances), if it is required. **Cloud provides an almost limitless**

- ✓ ***scalability,***
- ✓ ***availability,***
- ✓ ***computation power,***
- ✓ ***reliability***
- ✓ ***continuity.***

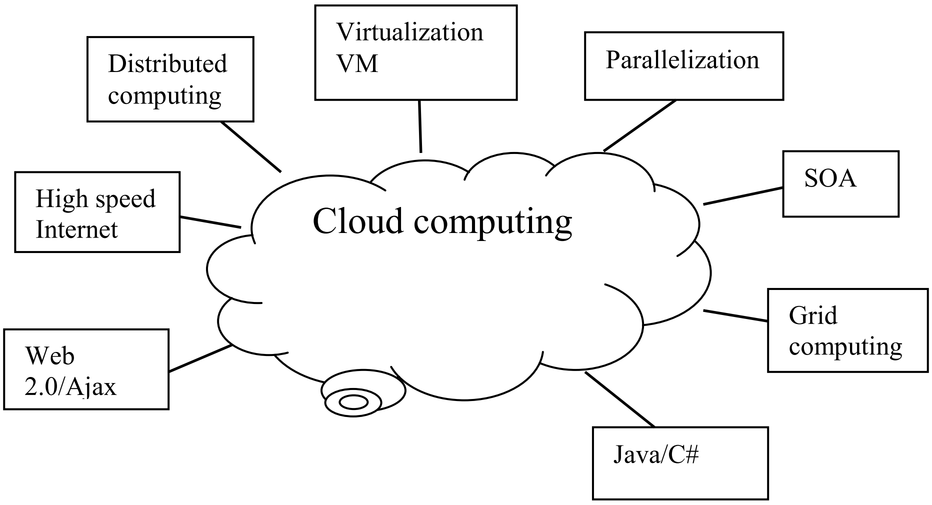


Fig. 8. Cloud computing technologies

Many years computer network technologies, which are basis for Cloud computing, were developing and continuously involving mostly by key companies like IBM (leader in computer architecture technologies, DBMS), Sun Microsystems (server technologies), Oracle, SAP (leader in commercial DBMS), VMWare (leader in commercial virtualization platforms) and others. The hardware and software for powerful DC were very expensive and available only for large companies. Cloud DCs were mostly internal private property of companies (nowadays, so called, Private Cloud). So, Cloud computing technologies existed many years before appeared this term “Cloud”. Therefore, Larry Elisson (Oracle Corporation) first told, that Cloud is a new name for advertising product, that are existing technologies and Oracle has presented it already in their solutions. But it is not so, Cloud computing has a revolution meaning for IT and leader companies were afraid to lose a big piece of their business. And in one year Oracle has presented their Cloud Platform. If before, magic powerful Cloud was reality only for IT giants, who were able to buy high cost complex software and hardware solutions from Oracle, Sun, SAP and VMWare, and, moreover, they should have an army of high level professional IT workers to administrate it. Now Cloud DC became reality for medium, small companies and even for common users.

The main drive toward Cloud computing came from the server prices falling and becoming more affordable high speed Internet (fiber/4G+ with Web 2.0), free virtualization platforms developing (Virtual Box). At first, many small professional DC were appeared, because reliable powerful remote virtualized servers became cheaper. Secondly, companies with super powerful Cloud DC were established (Amazon Web Service/Elastic Cloud, Google Cloud Service, iCloud). They offered to rent Cloud power (so called Public Cloud). In that case, companies/users do not need to buy an expensive hardware and software, or have Cloud server administrators. This idea enabled dream about professional Cloud DC for many users. But the question about security risks is still open.

Classes of cloud computing:

1. Private cloud – Powerful distributed Cloud Data Center, internal propriety of company.
2. Public cloud – Elastic Cloud, Google, iCloud. All information saved on external public resources.
3. Gibrid cloud (part of system in private cloud, part in public)

Type of cloud computing:

1. SaaS – software as a service. For example E-mail web service, on-line application. Web access to the applications.

2. PaaS- platform as a service. Provide platform from web. For example remote hosting with some need platform for software development and instances to развертывания it.

3. IaaS – infrastructure as a service. Provide infrastructure from web connection. For example, IT infrastructure, cloud hosting

4. CaaS – communication as a service. All communication from web with all kind of gadgets synchronized (PC at home+Smartphone, job: PC+corporate smartphone and laptop for travels). It provides access to your data via web account.

6.4. Conclusions for Vehicle Systems

Recent research in ADAS/CoDAS emphasizes the use of vehicle communications to improve driver assistance. As well as, modern transport networks tend to combine functionality of VANET and ITS [20] and use both V2V and V2I communications. Thereby, to summarize, Vehicle Networks tend to be more integrated, widespread and became a part of the global transportation system [47].

Moreover, the IoT paradigm opens up the new dimension for Vehicular Networks like a part of more global concept [57]. The opportunities of novel IoV vehicle services seems unlimited in the terms of data store volumes, immediately data access to huge amount of information, Cloud computing power, which enables using of sophisticated intelligent algorithms including neural networks, real-time context information analysis, Big data analytics [81].

For driver assistance IoV Cloud can result in the set of advantages:

- Service Oriented Architecture (SOA),
- full distributed client-server applications with advantages of server virtualization;
- high flexibility,
- high availability;
- high reliability of distributed computing;
- extremely high performance for server part of the IoT apps, where we can run heavy intelligent algorithms, including object detection, prediction, collision avoidance business intelligence (logic).
- high scalability of connected sensors (“things”) including through the databases scalability (for example, NoSQL DB);

Nowadays, the main challenge is to provide a reliable and high speed wireless connection between vehicle sensors and DataCenters (DC). The V2X WAVE communications are not enough for these goals. This is particularly important for real-time DAS in terms of latency of data transmission (position beaconing, video streaming). But the IoT protocols and next generation networks as LTE Advance + (4G, 5G+ networks) will enable the high-speed and reliable vehicle communication. In fact, the next generation of communication standard 5G (and more) as well as IoT paradigm are considered like a future steps for vehicle communications.

7. The SiDAS system proposal

The SiDAS design process and documentation includes project planning elements and techniques of ANSI Standard.

7.1. Project Restrictions

Scope restrictions. Current research deals with Safe Intelligent Driver Assistance System (SiDAS). The subject of the research is the transport information connectivity to improve traffic safety. The scope of the research is DAS, Vehicle networks and Internet of Vehicle interoperation in order to increase situation awareness and reliability of driver assistance.

Quality restrictions. SiDAS solution has to receive and process data flows from the cars and systems restricted within the State, and able to interconnect and interoperate with world scale Internet of Vehicles (IoV).

Time restrictions. Current research has a time frame of 3 years of doctorate studies.

Budget restrictions. The main principle of “zero cost” project: using open source software, platforms; free and trial versions, avoid the use of paid IOT/Cloud services.

7.2. Intended Audiences

The intended audiences of stakeholders for this research of the SiDAS include:

Researcher and state employees:

Researcher, who interest in the field of the transport networks, pedestrian detection;

State employees of transport departments;

Customer Representatives;

Technical support employees (Driver Support Service), who will provide a support of user interaction interface to the end road users.

Security Officers, who respond to potential security violations of the transport system;

IT professional and engineers of Intelligent Transportations (ITSs, VANETs):

Project Managers

Architects, whose overall architecture must meet the requirements specified in this research.

Designers, whose design must meet the requirements specified in this research.

Hardware Engineers, whose hardware components must implement the specified requirements,

Software Engineers (programmers), whose software components must implement the requirements specified in this SRS.

Quality Engineers (Testers, Usability Engineers), who must ensure the quality of its quality and usability requirements.

Drivers, who would like to take part in SiDAS practical approval.

Business or private individuals that would take part in a SiDAS development and implementation:

Search engine maps;

Transport information services and apps;

Transport agencies.

7.3. SiDAS General System Requirements

Implementation requirements. SiDAS solution has to be cost-effective and easy to maintain. System has to run both on distributed Data centers with SAN/NAS storage, as well as on the computers with server architectures (IA64) and PC architectures (x86-64).

SiDAS has to be easy for mass deployment, with a minimum required software and hardware for the end users. It should to minimize the volume of the applications and requires minimum of the hardware and software subsystems inside the cars.

Data Acquisition requirements. SiDAS system architecture has to allow evaluating different aspects of the traffic situation according both in-vehicle and infrastructure data in order to increase traffic safety. SiDAS solution has to receive and process data flows from the millions of cars and systems within the State scale, and be able to interoperate with world scale Internet of Vehicles. Thereby, system has to be high scalable and handle Big Data flows.

Business logic requirements. SiDAS business intelligence has to detect cars and pedestrians, analyze possibility of collision situations and provide events for driver notification in real-time mode. Software, which contains business logic for object detection, collision avoidance and emergency notification, has to be appropriate for server side (for example, run on application servers of the Cloud Data Center).

Architecture requirements. SiDAS has to be designed according to IoT Architecture Standards and models. The system has to support distributed architecture, using Cloud/Fog computing in order to realize Big Data processing.

Interconnection requirements. SiDAS has to be able interconnect with available ITSs and VANETs in the current road area, as well as with common equipment and driver gadgets architectures: x86-64 (PC, Laptop), ARM (Tablet, Smartphone, Mobile phone), Proposed system has to be able to interconnect for the most of common equipment and driver gadgets currently available in cars: navigators, car cameras, DVR and sensors with cellular connection/single board computers (Arduino, Raspberry Pi). SiDAS architecture has to have further ability to interconnect with Internet of Vehicles (IoV).

Communication technologies requirements. To realize interconnection requirements system has to support set of V2X communication Standards (WAVE, WPAN, ZigBee, DSRC, XMPP); protocols based on IoT concept (MQTT, CoAP, HTTP/2); connection over cellular networks; WLAN/LAN with S2S protocols for server interconnection. System has to provide for interconnection with Cloud/Fog Data Centers, Vehicle networks and cellular networks.

Thereby, general task of this research is development of scalable, powerful and flexible distributed driver assistance architecture able to evaluate information from different types of the traffic data sources in order to provide emergency driver notification, which low equipment requirements and low-cost for end users.

7.4. System proposal description

Our solution focuses on automobile driver assistance system for road safety. Our scope of interests is the intersection of the concepts Internet of things, V2X communications and safety (Fig. 9).

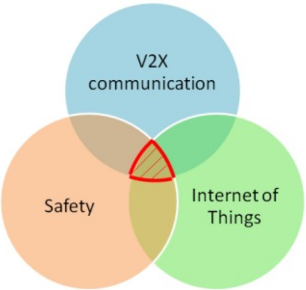


Fig. 9. Scope of the research interests

The proposed system do not has to depend on availability of high-cost equipment in the car and has to handle most of equipment currently available in cars: common models of car DVR, cameras, navigators and Smartphones, as well as able to provide data acquisition from infrastructure and in-vehicle systems to facilitate implementation of safety intelligence. The proposed solution has to searching for way to update the driver assistance by using modern Standards of VC (vehicle communications), widespread cellular network, IoT technologies and Cloud computation power to facilitate implementation of safety business intelligence.

The SiDAS concept model was developed based on IoT concept model according to our project objectives. The concept model is shown in Fig. 10.

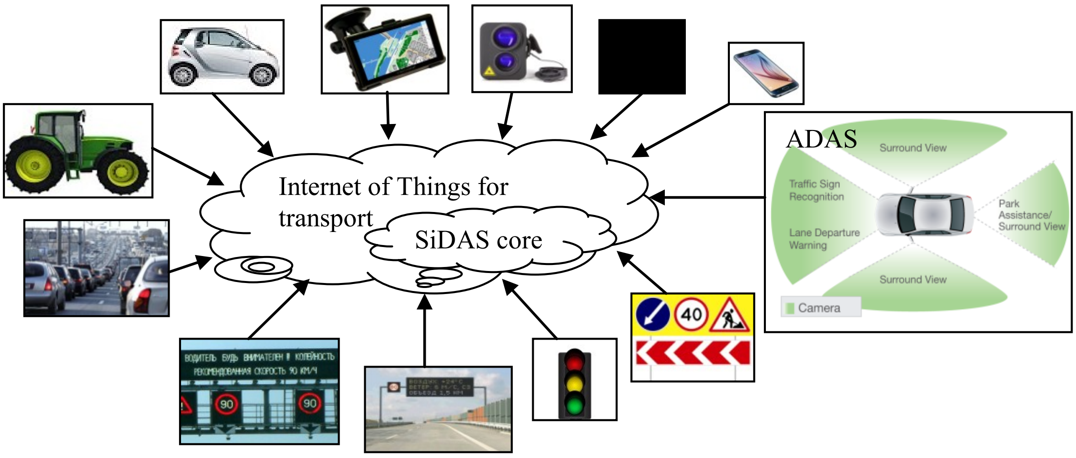


Fig. 10. SiDAS concept model

We propose to combine the different sources of information about the road situation via IoT. Original idea is using data from 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 for safety applications.

The idea of IoT-based driver assistance system is that cars, on-board system, sensors inside the car, driver devices (Laptop, Smartphone) will be one of the “things” in the IoT network –

Internet-of-vehicles (IoV). We suggest connecting vehicles and the current infrastructure with advanced technology (computing networks, sensors, information systems, intelligent algorithms) over IoT. This can be realized through connecting internet-enable devices, vehicles, Vehicle station of ITS systems with Internet-of-Thing by IoT protocols.

The designed system brings together data flows from different type of data sources. It can be

- ➢ data from car ADAS system,
- ➢ common driver sensors and devices in the car: car navigation system, car GPS receiver, car camera, driver`s Tablet, driver`s mobile phone;
- ➢ infrastructure information from street sensors, cameras, available Vehicle networks and ITS;
- ➢ other road user and pedestrian gadgets (mobile phones, Tablets);
- ➢ opportunity to include any other sources of information.

These devices can have a connection to the internet via different technologies: cellular network (GSM/UTMS/LTE), DSRS, WAVE, Wi-Fi, Zigbee. All these devices, systems and gadgets provide a wide range of useful data for safety goals.

The tasks of SiDAS platform are:

- detection of device/system;
- connection setup;
- device/system authentication;
- determining what kind of information we can receive from this device,
- data acquisition with different data formats;
- filtering/evaluation of the accuracy of information/prediction.
- data processing/running safety algorithms;
- real-time alarm about the dangers.

The most important SiDAS requirements:

- high availability of IoT services to connect devices/systems;
- supporting a wide range of communication technologies and protocols;
- provide appropriate time for up-link, processing and downlink for real-time notification;
- algorithms for data acquisition and DB have to support different data formats;
- provide security and data privacy;

7.5. Design Approach for the System Architecture

The set of methodologies is used in the design process of the system architecture [82]:

- ✓ IDEF modeling methodology;
- ✓ Data flows investigation;
- ✓ System development based on the IoT reference model and Standards.

The above-mentioned suggestions require that a new design approach be adopted in order to up-to-date Driver Assistance System and ensure its comparability with Internet of Things and Internet of Vehicles. It would make innovative DAS more flexible and usable by drivers and by vulnerable road users.

7.5.1. IDEF Modelling Approach for the SiDAS Design

It is used Integration Definition (IDEF) modeling methodology for the architecture design process. IDEF is a set of powerful modeling methods and modeling languages most used to design and analyze highly complex systems. IDEF0 is the part of the IDEF and built on the functional modeling language Structured Analysis and Design Technique (SADT). IDEF0 is intended for analysis, development and integration of the information systems. For new systems, it may be used to define the requirements, reasoned solution decisions and specify the functions (actions).

In Fig. 11 the system being developed presents in function modeling language (IDEF0 Diagram).

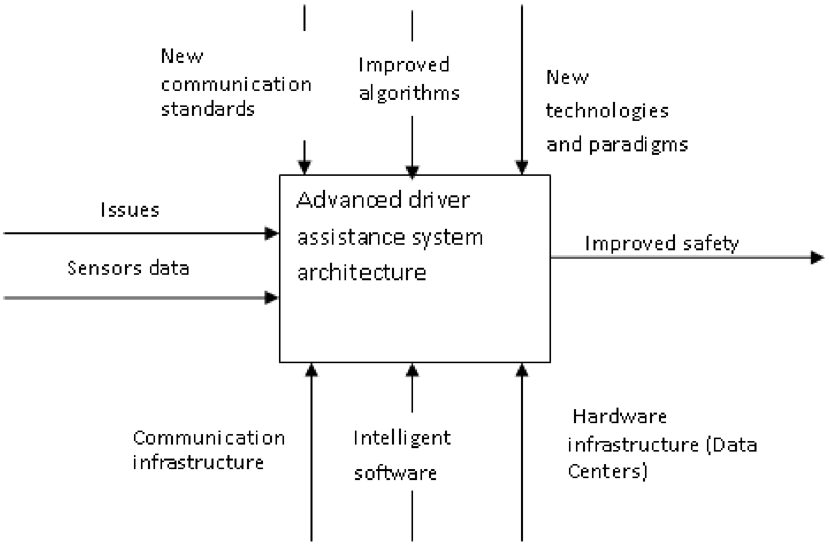


Fig. 11. Function model (IDEF0 Diagram)

The IDEF0 diagram describes the function model of the business process of SiDAS architecture design. The main functions (or actions) are represented on the diagram by the box. The IDEF0 has 4 arrows: the input, the output, the control and the mechanisms.

The data and objects that inter-relate those functions are represented by arrows:

- The input of the system on IDEF0 diagram is the data from the sensors and the issues we need to solve.
- The output of the system on IDEF0 diagram is the improved safety.
- The control of IDEF0 diagram is the new communication standards, improved algorithms and new technologies paradigms.
- The mechanisms of IDEF0 are communication infrastructure, intelligent software and hardware infrastructure.

New technologies are Internet-of-Thing and Internet-of-Everything, Cloud computing, modern V2X communications standards, VANET investigation. To realize V2X communication We propose to use on-board sensors inside the car, as well as infrastructure cameras network. A more detailing function diagram is presented in Fig. 12.

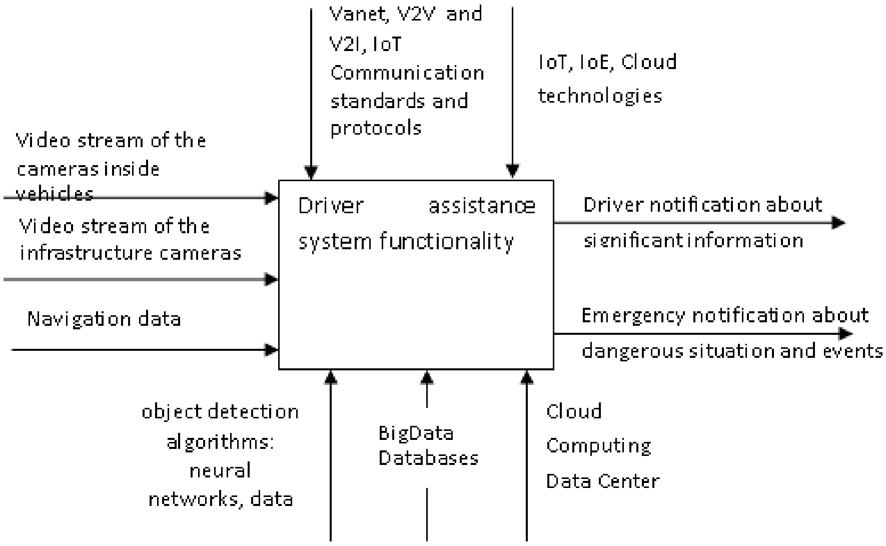


Fig. 12. Detailed function model IDEF0

The designed system architecture based on our IDEF0 model is shown in Fig. 13. The proposed system contains specific algorithms for IoT V2X communication which allows to collect different kind of signals from different devices (“things”: vehicles, cameras, monitoring sensors, GPS enable devices).

System is built according to the objective of maximum standardization. We consider cars have reachable intelligent transportation system network (ITS). Usually ITS consist of Vehicle Station (VS), Road Station (RS) or Road Side Unit (RSU) and Server.

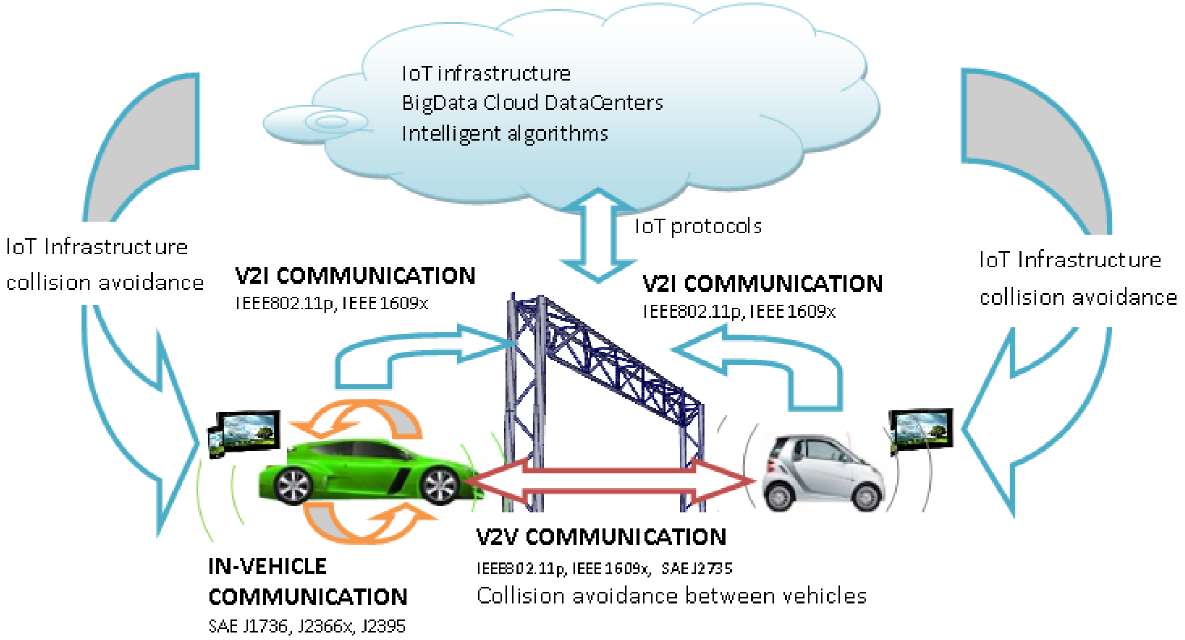


Fig. 13. Proposed V2X IoT based system architecture

7.5.2. Data flow analysis for the proposed solution

Proposed system evaluates different aspects of the traffic situation due to video and navigation data to increase safety (Fig. 14).

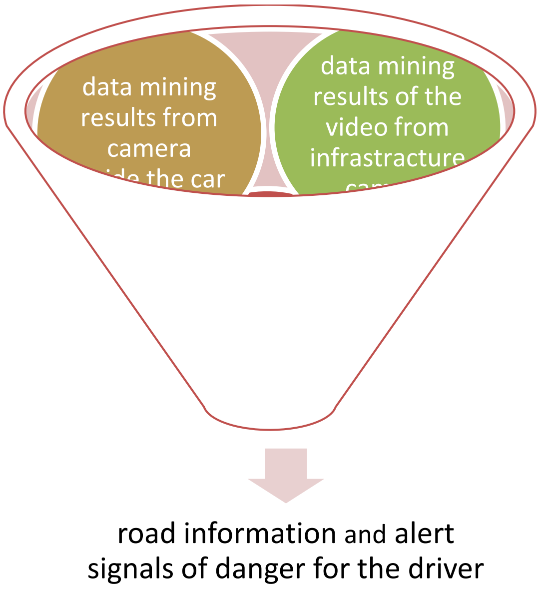


Fig. 14. Scheme of information flows

Connection with Internet, powerful Data Centers and intelligent algorithms allows us to create a fast, low volume and low-cost hardware and software system for drivability (Fig. 15).

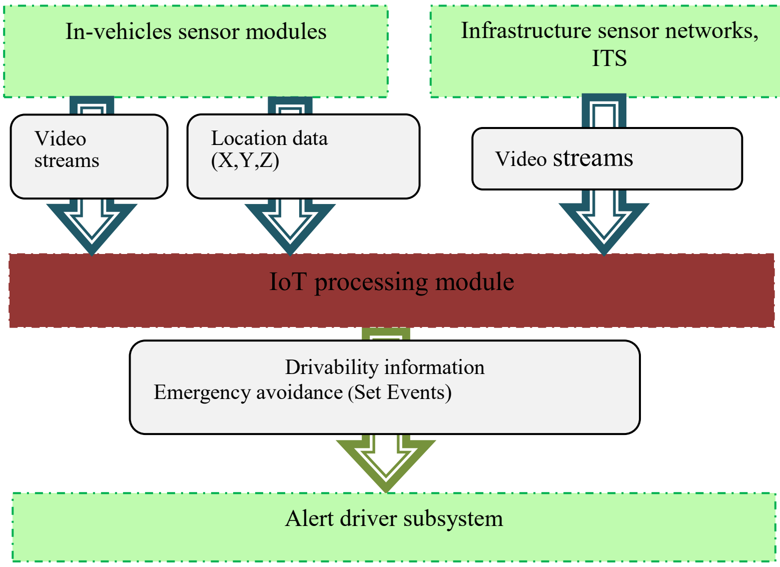


Fig. 15. Data Flow Diagram in driver assistance system architecture

7.5.3. IoT ARM for Proposed System

We have designed IoT architecture for our Driver Assistance System based on IoT reference model (ARM) and according to the standard ETSI 302 665 ITS [83] and IoT Reference Architecture [84] (Fig. 16) to ensure compatibility with other IoV decision in the future. The standard presents network layers for vehicle networks. In the standard IoT architecture have to include 4 layers [83]: “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. IoT reference architecture is include 7 levels: device level, communication level, IoT service, virtual environment, IoT process management, Service organization, Management, Security and Application level.

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 levels describe structure of IoT services and provide possibility to control these services.

IoT Management and Service Organization levels enable SOA for the IoT system. We can manage services: add, change and remove services, use different rules.

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).

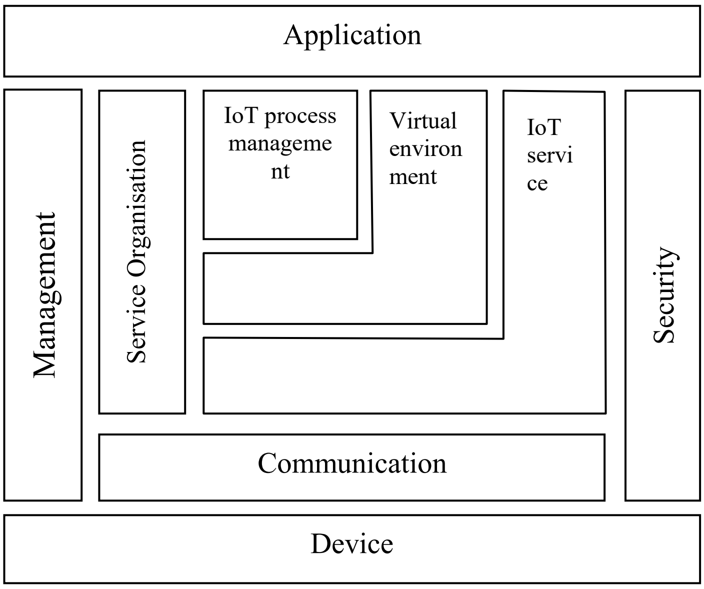


Fig. 16. IoT architecture reference model [84]

The detailed IoT reference architecture for our SiDAS system presents in Fig. 17.

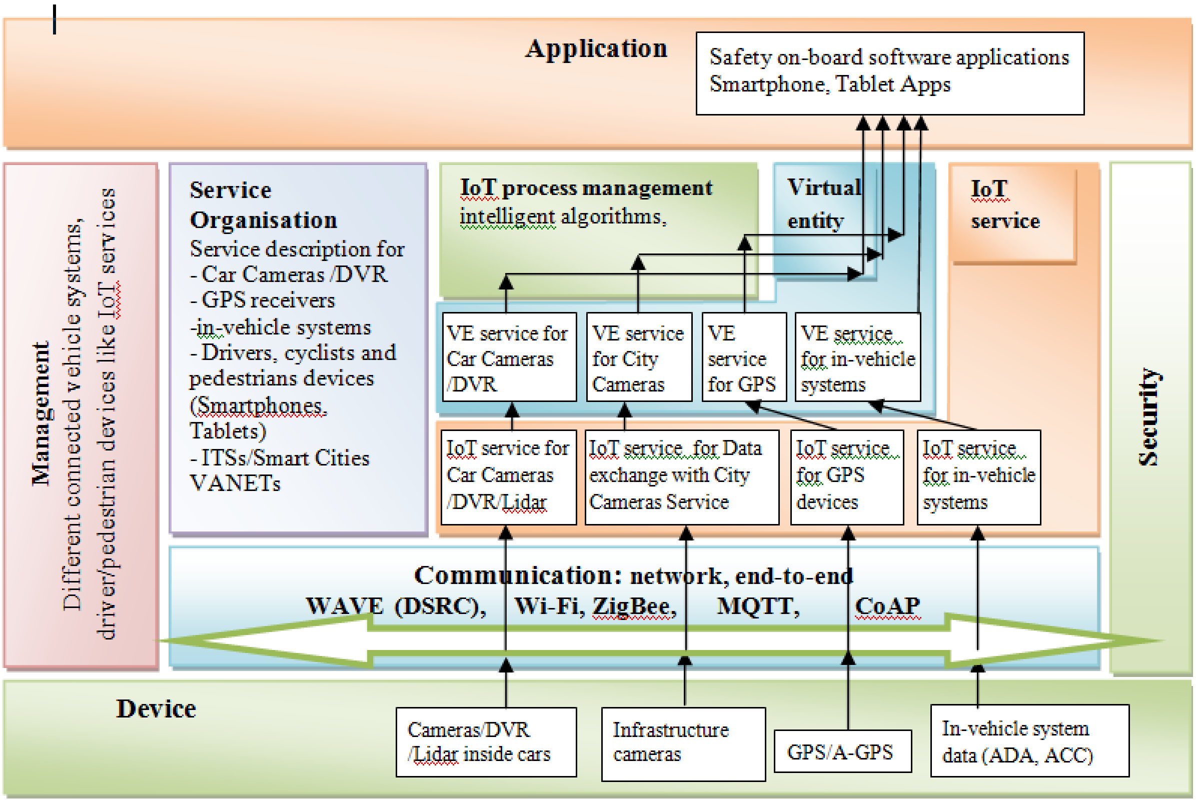


Fig. 17. **Proposed system ARM network levels according to IoT ARM for SiDAS proposal**

7.5.3.1. Device level: Sensors

Sensors module consists of sensors inside the car (in-vehicle sensor) and road infrastructure sensors (Fig. 18). The most important sensors are cameras like IP camera or DVR. Camera can have CCD matrix, CMOS matrix for high-speed objects, it can have infrared mode [85].

Navigation sensors can be GPS receiver, low-cost models strapdown inertial navigation systems (INS) based on micromechanical gyroscopes with GPS correction or mobile enable device with A-GPS technology.

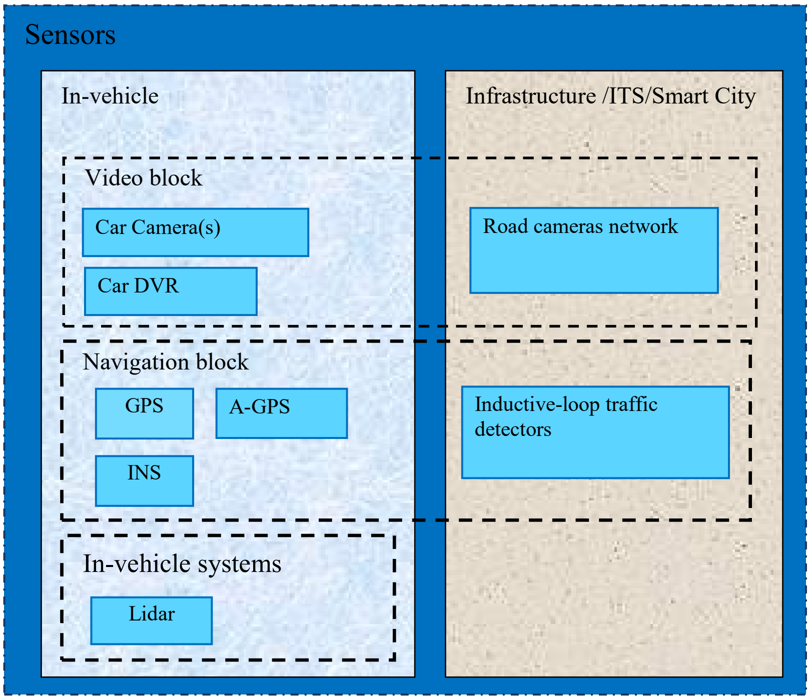


Fig. 18. **Proposed system device level: sensors**

The methods for data fusion from multiple sensors is proposed in [86].

7.5.3.2. 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. 13 is shown that cars can be connected each other by V2V using:

- wireless protocols for vehicles WAVE (over IEEE 802.11p (PSY and MAC) [32], IEEE 1609x (media level data, network, transport) [87], [88]),
- DSRC (SAE J2735 APP).

Vehicles can be connected with infrastructure ITS Road station through V2I connection using any protocols:

- WiFi (PSY MAC IEEE 802.11),
- enhanced Wi-Fi (IEEE 802.11b) [89],
- WAVE (IEEE 802.11p) [32],
- ZigBee (IEEE 802.15.4) [70], [89].

V2I on APP OSI layer uses IoT protocols: MQTT [71], CoAP [72], HTML/2 [73]. As well as Road Stations (RS) is connected to IoT infrastructure using IoT protocols MQTT, CoAP or HTML/2.

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 (Fig. 7).

7.5.3.3. IoT communication with "things"

Data transmission from sensors to the IoT requires a special microchip and special protocols. This microchip has to support IoT protocols as well as different required interfaces of the connecting "thing". For this goal we can use Arduino microchip or Raspberry Pi minicomputer. We need suitable IoT protocols over of IP connection. The most appropriate IoT protocols for vehicle network are MQTT [71], CoAP [72] and like network protocol HTTP/2 [73], [89].

Vehicle networks and ITSs require a gateway for interoperation with IoT services. An example of the gateway structure for connection Ethernet-WiFi, than WiFi-(ZigBee+CoAP) is presented in Fig. 19.

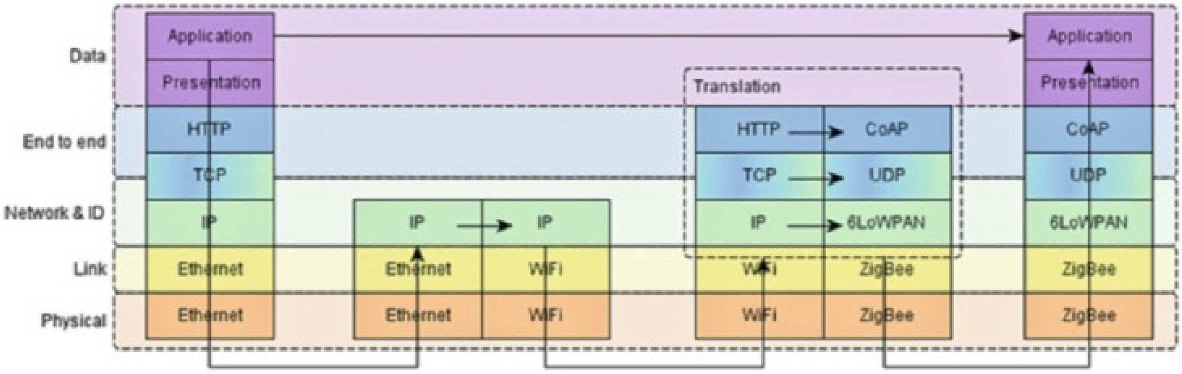


Fig. 19. Gateway configuration

7.5.3.4. *Application Level: Proposed Apps Structure for Safety Problem and Issues*

The proposed system is focused on the road safety mission of V2X communication. Ensuring safety is very important function of communication vehicles. The idea of V2V communication is based on the observation that the vehicle can detect a potential danger and warns other cars without human participation mostly using special microchips and special protocols. The danger can be recognized on the basis of the evaluation of the cars movements and drivers behavior. Appropriate sensors detect the abrupt change of direction of movement, the speed, sharp pressing the brake pedal, etc.

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. 20). The warning mechanisms were studied in [90] and the authors proposed multimodal redundant warnings.

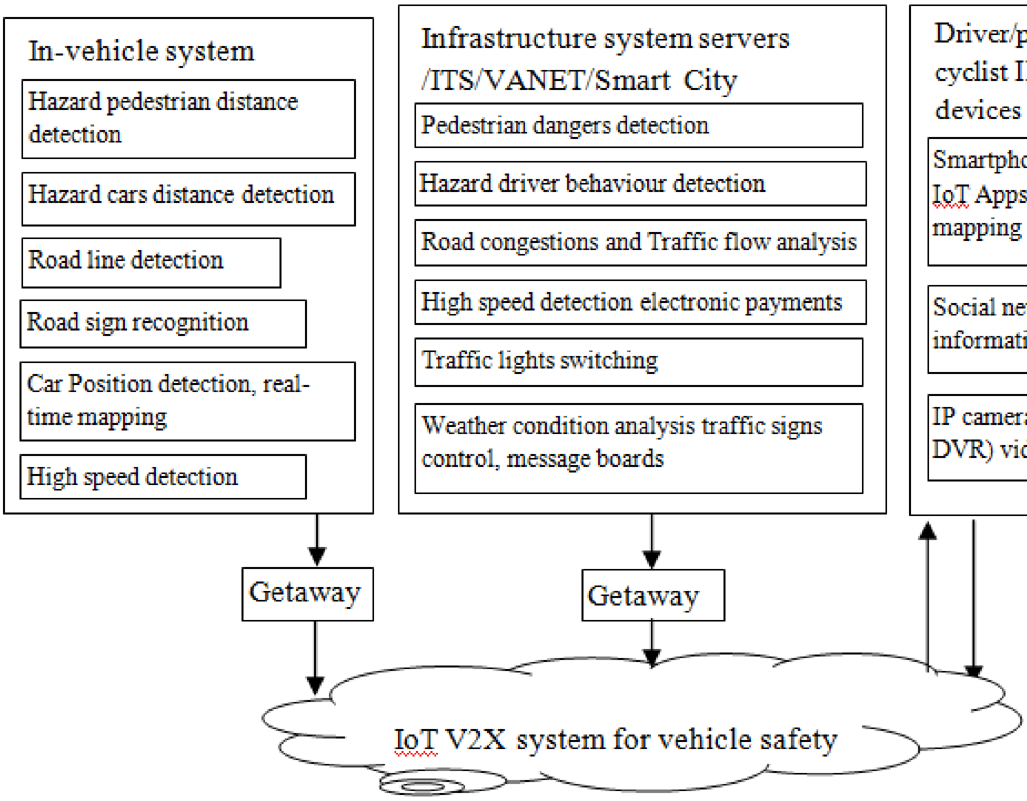


Fig. 20. Application level and connection with IoT

A number of these applications have already been implemented on modern cars using video cameras and radars, for example in the system of emergency braking assistance when rebuilding, recognition of traffic signs. 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. 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.

7.5.3.5. 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.

7.6. Conclusions for the SiDAS proposal

We have proposed an approach for the design of the cooperative intelligent DAS (SIDAS) architecture and a structure based on this approach.

We have improved V2X communications with the IoT concept. 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 an IoT reference architecture model and modern communication standards. Therefore, the proposed system design ensures comparability with different kinds of existing in-vehicle and V2X systems. We are confident that it will allow the use of important information from other networks for road safety in the future. It could be Smart grids, VANET, mobile networks, and even context information from business, education or social networks. We have shown the way to present the common driver`s sensors and gadgets in the car as “things” in the IoT. These common devices can give us a lot of information to improve safety.

In the further work we expect enormous opportunities to enhance safety and provide for the driver wide-range warning information as results of Big data analysis, event notification, significant context information would be available. It can be danger driver alerts, access to appropriate infrastructure information about current road, congestions, significant events 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 vehicles.

8. CASE STUDIES: safety apps for the SiDAS collision avoidance system

SiDAS aim to enhance safety of the road users including pedestrians, drivers, and cyclists. In this section it will be shown the safety and reliability enhances of driver warning using SiDAS approach with IoT based V2X communication on the examples of collision scenarios. The approach based on data fusion from the multiple sensors, systems and gadgets. The novel approach takes into account data from in-vehicle sensors as well as infrastructure sensors.

In the test cases the considered in-vehicle sensors are

- Car navigation system with GPS receiver and INS / only GPS receiver;
- Car camera (or digital video recorder),
- Infrastructure sensors: infrastructure camera;
- Driver`s Smartphone.
- Pedestrian`s Smartphone;

The information from all these different types of the sensors is combined, processed and presented to the driver in the user friendly way (warning on Smartphone app).

8.1. Case Study 1: SiDAS Collision Avoidance for Parked Car

8.1.1. Scenario 1

Let consider the common collision scenario, than a car 2 depart from a parking lot (Fig. 21). The other moving car 1 is not visible for the driver of the departing car 2 because of other parking cars or building angle. And the driver of the moving car 1 does not know that driver of parked car 2 start to depart.

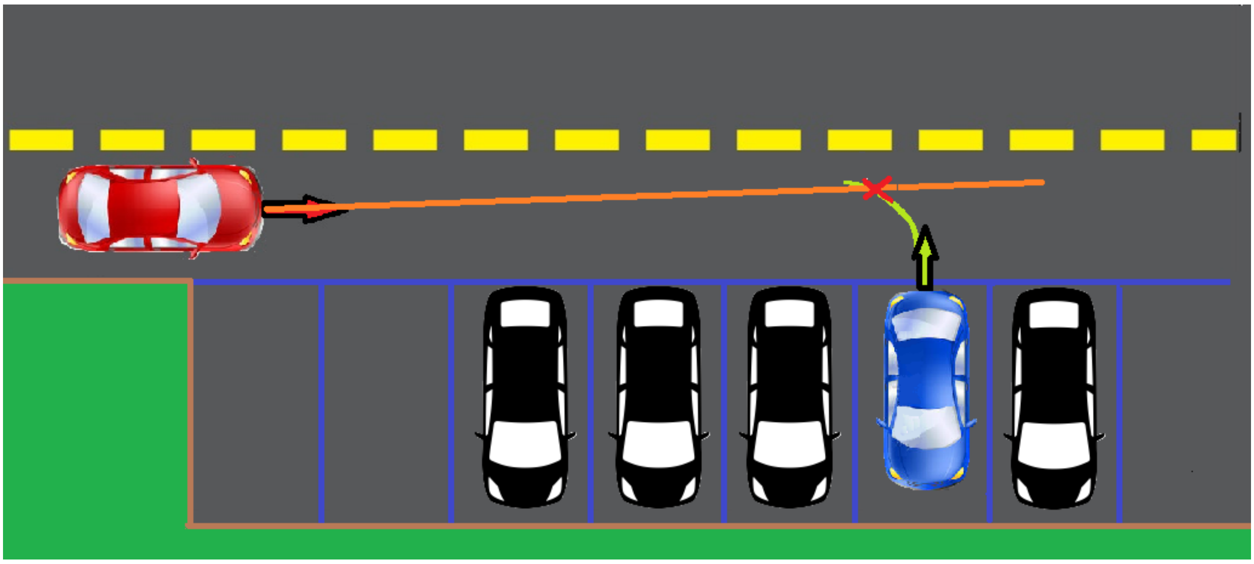


Fig. 21. Scenario 1: car go away from parking place

8.1.2. The classic vehicle network architecture solutions of collision avoidance system between cars

Usually V2V communication is used for the collision avoidance between surrounding cars [7]. The classic ITS and VANET structure requires the installation of the vehicle modules (VS) in the car 1 and car 2. The architecture of ITS system was considered in the previous sections.

Sensors for collision avoidance system

Collision avoidance systems usually need to define vehicles position or distance between cars. The sensors used for vehicle position detection are INS [25], WiFi, GPS, beaconing by Smartphone A-GPS technology [28], camera. In [91] is proposed a INS/GPS time synchronization method.

Communications for collision avoidance

The classic technologies using for vehicle-to-X (V2X) communications are: WAVE (IEEE 802.11p), IEEE 802.11g [27], DSRC, ZigBee (IEEE 802.15.4).

A set of collision avoidance system based on cellular networks was developed. In [33] is considered the communication for collision avoidance over 4G/LTE. Communications for emergency vehicle applications over 5G networks were presented in [92]. Nowadays, IoT is considered like a promising paradigm to improve significantly emerging communications. In particular, IoT enabled us to use data from a wide range of distributed sensors (in-vehicle as well as infrastructure).

Classic ITS/VANET architecture for V2I collision avoidance

The classic ITS/VANET collision avoidance architecture for our test case is presented in the **Fig. 22**. Then cars far from each other, the vehicle stations of the car 1 and car 2 is sending their current information and location beaconing to the Road Side Unit (RSU). If vehicles close up to communication distance (d_{com}), vehicles will create direct VANET connection by V2V communication. In this scenario if distance less than d_{com}. we should take into account DSRC delay for communication between the car`s vehicle station (VS). In the case than distance more than $d_{com}$ , we take into account delay for communication between car`s VS with road side unit (RSU) and also communication delay from RSU to server side.

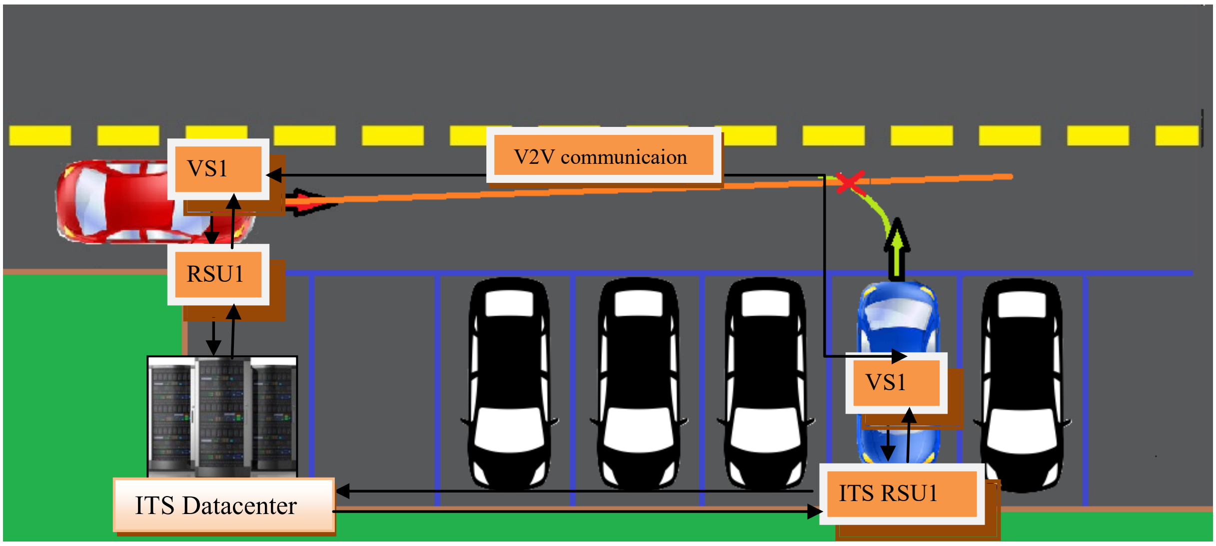


Fig. 22. Classic ITS/VANET solution

8.1.3. Proposed SiDAS parked car collision avoidance Architecture

8.1.3.1. Test case 1.1. Parked car collision avoidance Architecture with car GPS

In this section is presented the solution for parked car collision avoidance subsystem based on data from in-vehicle GPS sensors and V2X communications. The architecture is presented in the Fig. 23. We suppose that moving car 1 and parking car 2 have GPS receivers. We are increasing situation awareness via the fusion solution taking into account the information from GPS car sensor 1 and GPS sensor 2.

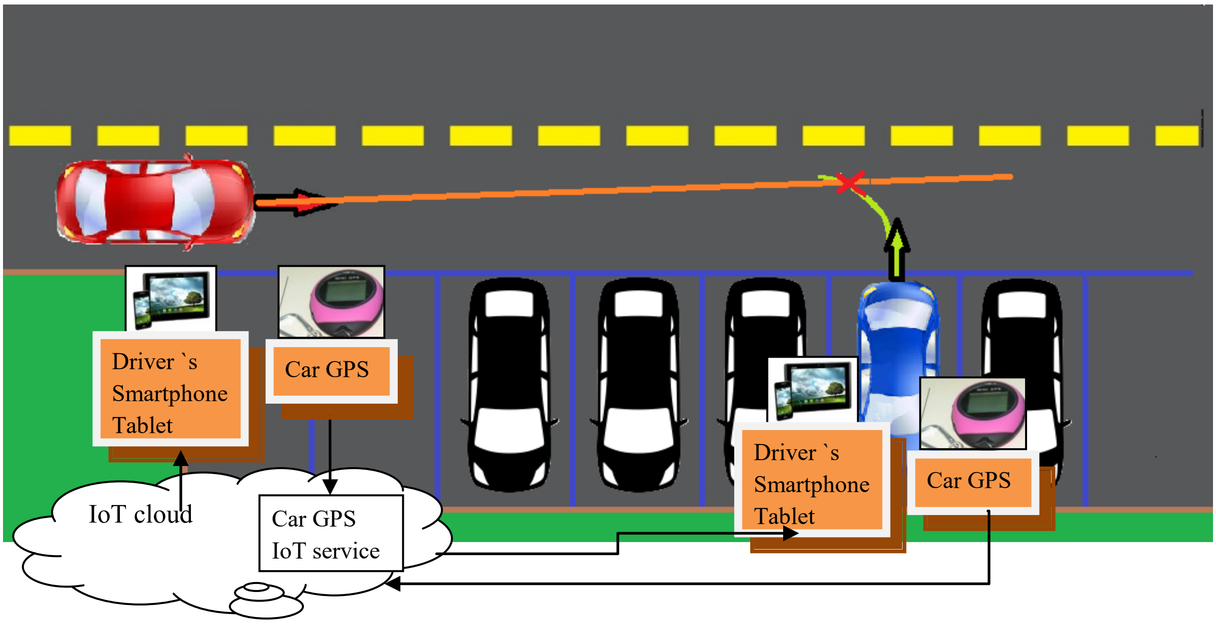


Fig. 23. Parked car collision avoidance solution using GPS and IoT

The sensors of the moving car are not able to detect the departing car because of it hide in other parking car (or it might be some other object, like an angle of some building). However, the departing car can be detected from car GPS sensor.

We use data fusion from car1 GPS and car2 GPS via V2X communication using IoT.

All row data from sensors have to be filtered by Extended Kalman Filter in order to correct errors. Moreover, the modern GPS sensors and cameras have their own internal filters and they provide pre-processed data on the output. In our simulations are used simulated sensor data and simulated errors.

The first car position (x_{car1}, y_{car1}) and second car position (x_{car2}, y_{car2}) are beaconing to the IoT cloud database. We suppose that the driver connects car GPS sensors to the IoT car GPS service. The data about position of the car1 and car2 are beaconing to the IoT DC by the Car GPS IoT-service. The beaconing frequency is situation adaptive and use approach from the paper [28]. The frequency depends on the mode, danger degree of situation and the car speed (normally, every 1 second). The collision avoidance algorithm is run in IoT-service. If the algorithm detects the danger situation it sends the warning message to the driver Smartphone/tablet for both cars.

For our test case 1.1 the structure of data transmission is presented in Fig. 24.

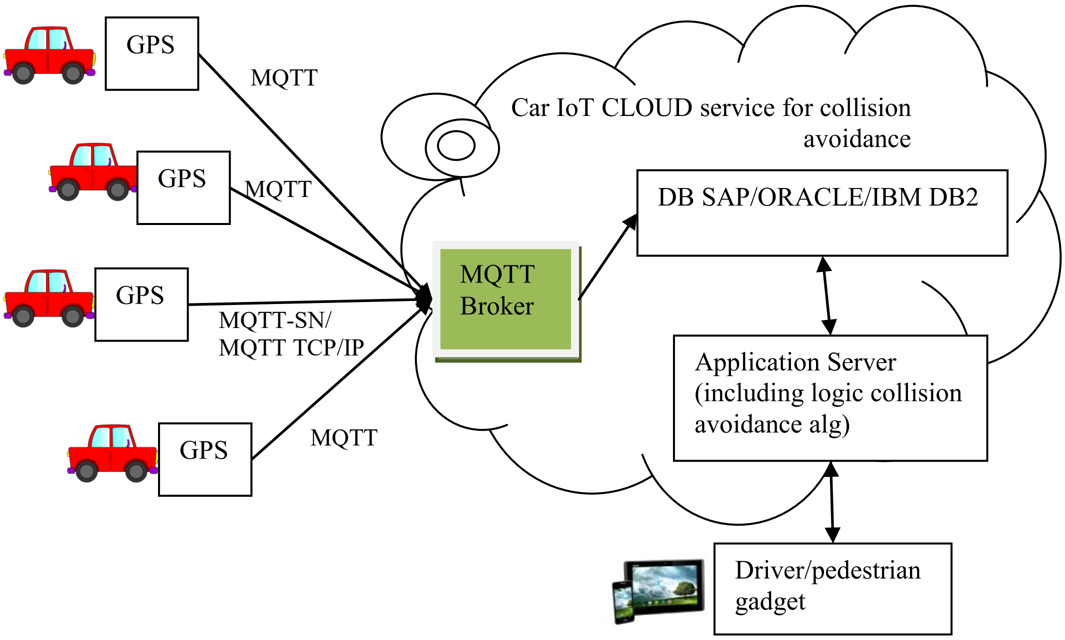


Fig. 24. Test case 1.1 Car collision avoidance. Car position beaconing to the MQTT broker

MQTT (Message Queue Telemetry Transport) protocol is chosen for beaconing as a most appropriate protocol for critical safety application, because of MQTT supports QoS levels. So, MQTT can guarantee the message delivery, as well as submit about the failures. Thereby, MQTT use will increase the reliability of the driver assistance system. Also, MQTT enables the different QoS level, which is very interesting opportunity. It would be possible to modify protocol delay for message in according to its critical level and time constraints. Moreover, MQTT is very flexible and works both over TCP and UDP (MQTT-SN) transport. It allows to connect devices with TCP/IP stack and simple devices without it. MQTT publish-subscribe model enable “event messages”, message do not need request as in CoAP, HTTP/2.

According to the technical requirements, SiDAS has to provide data acquisition from millions of vehicles, therefore, heavy DBMS has chosen. IoT CDC enables using any type of the data storage: light variants of DB like MySQL (MySQL is also DB), Microsoft SQL, Postgre, as well as heavy professional DB SAP/Oracle/IBM. Among the heavy DB, SAP has chosen to provide data store for collected information. Any heavy DB will be appropriate choice, but Oracle the author knows enough, IBM has a bad ergonomic, and SAP has promising DBMS engine. (Previously, SAP DB solutions were based on Oracle engine). SAP solutions widely used for bank platforms, cellular platforms and government platforms. It is able to provide super scalable and reliable platform for millions of clients/users and millions of billing transactions, calls, messages in the scale of States. It is possible to install BD SAP on x86-64 architecture or one server with several VM, but it will not allows to realize required scalability, reliability and continuously. The Cloud computing Platform will be appropriate choice. Data have to be further processed in order to define the potential danger situations. Thereby, the Cloud Data Center (CDC) needs to provide scalable and distributed data store and extremely powerful processing of huge amounts of data.

According to the technical requirements system has to provide data acquisition from various types of devices in different formats and their real-time processing. The common relational database is not able to provide appropriate work with different data formats, as well as real-time “hot” data processing on current instance (usually the copy of instance need for analytic requests). The NoSQL DB able to fix these issues.

The NoSQL DB SAP Hana has chosen in order to meet these requirements, With DB Hana, the data will be prepared for further BigData analytics. SAP HANA combines relational properties of DB with NoSQL, it able to use both SQL and WIPE languages on one copy of DB instance (so named, in-memory)! DBMS HANA provides analytics directly on that copy DB, where hot real-time transactions are provided!

In this test case we use only structured GPS data. For structured GPS data, I suggest to use in-memory smart data streaming of DBMS HANA. I suggest following structure (Fig. 25):

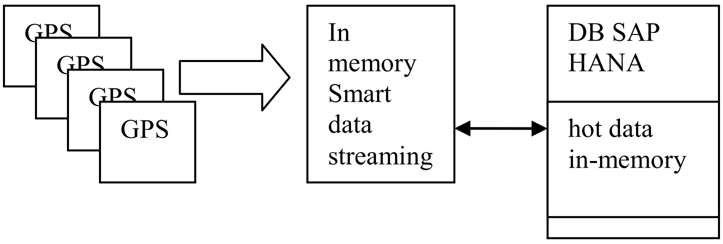


Fig. 25. DB Data transmission structure for structured data (GPS).

SAP HANA provides the support “scale out” technology and it is able to take place on several instances, which is important for Big Data processing in real-time.

8.1.3.1.1. *Analysis of the collision time intervals for systems based on IoT*

The most important parameters for collision avoidance are a time to collision and time margin, which driver has before to start braking. Also, an available time for the collision avoidance calculation and communication should be taking into account for the proposed architecture. Therefore, it is important to evaluate a time intervals and time margin, which has a driver, for the collision scenario. Also we should evaluate and take into account the time available for car position beaconing, transmission of data using V2X and IoT communications, calculations and warning for the proposed architecture.

In this section we will present a physical analysis of the different time intervals that occur in an accident scenario as shown in **Fig. 56**. The study is focus on the intervals from data acquisition moment until the probable collision moment.

Let us suppose, that the car1 is travelling in a straight line (road is a line) with the constant speed $\vec{v}_{car1} = const$ and without acceleration $\vec{a}_{car1} = 0$, and the vehicle move towards to the probable collision point (x'_{coll}, y'_{coll}) in the GPS coordinates. In the road coordinate system probable collision point is (x_{coll},0), projection of the vehicle speed on the road axis is (V_{car1},0).

We can approximate movement of the car 2. We suppose that departing car 2 go away from the parking lot with the speed $\vec{v}_{car2}$ and with acceleration $\vec{a}_{car2}$, which is perpendicular to the road. So, in the road coordinate system (axis x is along the road), projection of the speed of the car 2 on the road axis is 0: V_{car2x}=0, $\vec{v}_{car2}$ =(0, V_{car2y}). During the departing manoeuvre of the car2 x-coordinate do not change significantly, therefore we can suppose that probable collision point is (x_{car2},0) in order to simplify the calculations,

a) First let consider a case than the ***driver of the car1 do not aware about the collision risk***, ***car2 will be on the road*** in the time t_{coll} for the car (Fig. 26).

If we suppose that car motion is a uniform linear motion with acceleration $a_{car}=0$

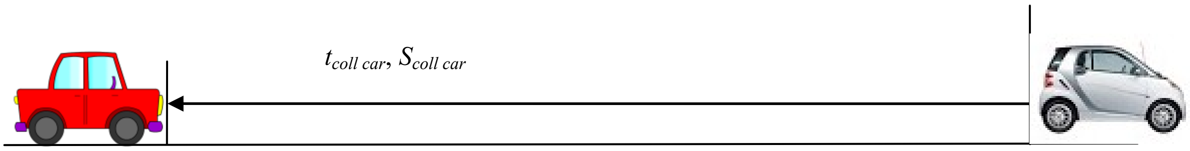


Fig. 26. Time intervals without collision avoidance warning

(V_{car}=const):

$$t_{coll\ car} = {S_{coll\ car}}/{V_{car}} = {|x_{car1} - x_{car2}|}/{V_{car1}}$$

where

t_{coll} – is the predicted time frame until the probable collision moment (time to collision), it is the whole time frame in which car will reach the probable collision point (x_{coll}, 0), time to collision;

$S_{coll\ car}$ – car displacement from the current point to the collision point (= distance in our case of linear motion).

b) If ***driver aware about the probable collision situation***, time model is so (Fig. 27):

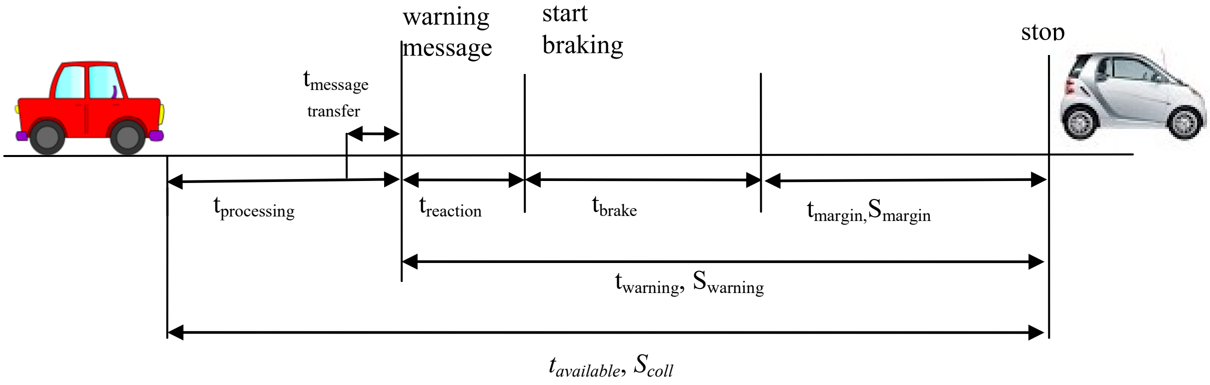


Fig. 27. Time intervals with the collision avoidance warning for $t_{margin}>0$

where:

$t_{available}$ – is the whole time period which system have the avoid collision in the case than the driver have SiDAS collision avoidance, which aware the driver about the dangerous situation. Let note, that $t_{available}$ for aware driver is different from the $t_{collision}$ for unaware driver ($S_{collision}$ is the same).

$t_{processing}$ – is the time for detection of the car position/pedestrian position (time for beaconing), for data transmission to the IoT Cloud, calculations and transmission of the warning message to the driver/pedestrian.

$t_{warning}$ – is the time from warning moment to the collision point.

$t_{reaction}$ – reaction time of the driver and car transmission.

t_{margin} – time margin which system have.

t_{brake} – time to full stop with a maximum brake force

8.1.1.1.1.1. Processing time

Let consider the processing time

$$t_{process} = t_{comm} + t_{comp},$$

where t_{comm} is the communication time for transmitting the beacon message about car position to cloud server and the collision alert message from cloud to Smartphone,

t_{comp} is the time for computation required to predict a probable collision.

8.1.1.1.1.2. Communication time for IoT based system

We propose formula for communication time calculation for IoT based systems taking into account infrastructure and car information like:

$$t_{comm} = max\,\{,t_{Sc1\,DT}, \dots, t_{Scn\,DT}\} + t_{emerg\,DT}$$

$\{t_{Sc1\,DT}, \dots, t_{Scn\,DT}\}$ is the time spent for transmitting data from the car sensors ($S_1,\dots S_n$) to the IoT service;

We are considered the communication time for the case study 1.1.:

$$t_{comm} = max\,\{t_{car1\,DT}, t_{car2\,DT}\} + t_{emerg\,DT}$$

t_{car1DT}, t_{car1DT} – time spent transmitting the data from the car`s sensors (GPS, camera, DVR) to the IoT cloud service.

$t_{emerg\ DTt}$ – the time spent transmitting an emergency driver alert.

1) *Let us consider t_{carDT}*

   For the test case 1.1 we suppose that car data is only GPS beacons and they are transmitting to the IoT Cloud. Also we suppose, that the communication channel from the car to the IoT server is over 4G/LTE network. So,

$$t_{car\ DT} = t_{car\ IoT\ SR} + t_{car\ IoT\ DT} = t_{car\ IoT\ SR} + t_{carLTE\ DT} + t_{carIoT\ prot\ delay}$$

where

$t_{car\ IoT\ SR}$ (server response time) - is the average ping response time to IoT service. Usually we do not take into account the ping response. But IoT ping latency can be quite significant, because of IoT service located in the remote Cloud DC of ICP provider. It might be the huge geographical distance between the sensors and remote IoT Cloud services (in other countries).Therefore, IoT time response is considered below.

$t_{car\ IoT\ DT}$ (data transmission) – time spent transmitting car data in IoT Cloud.

For our scenario data transmission over LTE $t_{car\ IoT\ DT}$ consist of data transmission time over LTE $t_{car\ LTE\ DT}$ and data transmission over IoT like IoT protocol delay $t_{carIoT\ prot\ delay}$.

$$t_{car\ IoT\ DT} = t_{carLTE\ DT} + t_{carIoT\ prot\ delay}$$

2) *Let us consider t_{emerg}*

   For test case 1.1 we suppose that driver alert is going over LTE, so,

$t_{emerg\ DTt} = t_{LTE\ transm}$

3) *So, communication time for our test case*

$$t_{comm} = t_{car\ IoT\ SR} + 2 * t_{carLTE\ DT} + t_{carIoT\ prot\ DT}$$

8.1.1.1.1.3. LTE communication delay

The delay of LTE is 50Mbps for uplink and 100Mbps for downlink [33].

As was mention before, the emergency driver alert is transmitting over LTE. We suppose $t_{LTEtransm}$ the time spent transmitting emerging driver alert over LTE.

The throughput of LTE based on the 3GPP standard is

$$t_{LTEtransm} = {}^{S}\!/_{R_{uplink}},$$

where

S – is the size of a beacon/collision alert message.

R_{uplink} – is uplink network bitrate available for each road users LTE network.

We suppose the size of messages according to [28]: $S = 0.8$ Kbit, max $R_{uplink} = 50$ Mbps for LTE (5 Mbps effective).

It followed, that:

$$t_{LTEtransm} = 1.6 \times 10^{-4}\ s = 0.16\ ms$$

8.1.1.1.1.4. IoT server response delay

The response of the IoT service we can suppose equal to a Cloud time response, which according to [28] and [33]

$$t_{IoTSR} \approx 50\ ms$$

But to evaluate the IoT server delay more precise we have used IoT simulation. We can measure this value by IoT network simulator, but let us provide the more real world simulations by IoT platform and real IoT broker.

8.1.1.1.1.5. MQTT latency simulation in close to real world conditions

The IoT protocol delay is shown in this section.

Let me describe the foundation of the MQTT. MQTT provide broadcast mode with publish/subscribe model. MQTT has a broker and clients. MQTT client can be publisher, subscriber or BOTH publisher and subscriber. Publisher can publish message in broadcast mode (in our case it can be GPS sensor data, video and so on). Subscriber can subscribe to receive some type of data from the “things". Broker catches these messages and sends it to Subscriber/subscribers. The structure of MQTT is shown in Fig. 28.

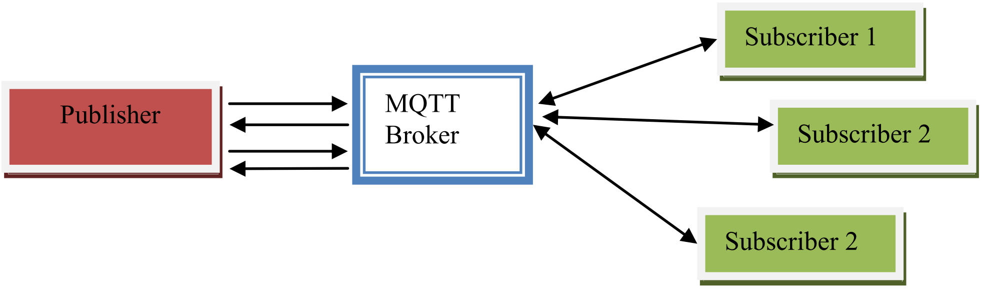


Fig. 28. MQTT publish/subscribe

MQTT is an app level protocol, it works over TCP/IP and usually uses the port 8883. MQTT has three QoS (Quality of Service) levels of message transaction.

QoS 0 – at most once. Publisher sends the message to the broker only one time the message and do not waiting for the answer (Fig. 29);

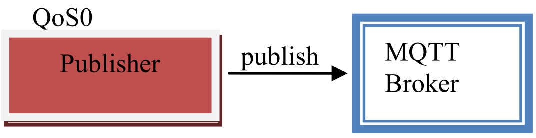


Fig. 29. MQTT QoS0

QoS 1 – at least once. Publisher sends the message and waiting for answer from the broker (puback), that message was delivered (Fig. 30);

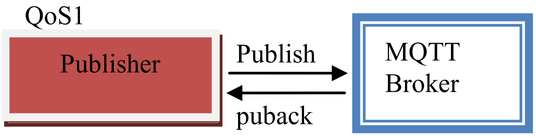


Fig. 30. MQTT QoS1

QoS 2 – exactly once. QoS2 exclude probability of message duplication (overlap). Publisher sends the message package with message ID to MQTT Broker and waiting for answer from the broker (puback), that package was delivered. Then, in order to minimize duplication, publisher sends pubrel with the same package ID and receives pubcom about the end of transaction (Fig. 31).

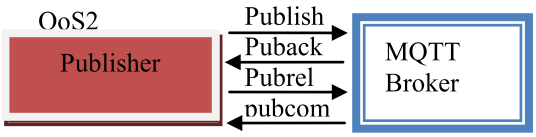


Fig. 31. MQTT QoS2

8.1.1.1.1.6. MQTT Publish latency

We used a real public IoT Broker in the Cloud DC iot.eclipse.org:1883 to provide the simulation that more approximated to the real world conditions. In addition, IoT simulator was used to simulate the sensors and data transmission from the sensors to the Broker.

1) *MQTT Publish delay simulation QoS1*

Simulation parameters:

```
Protocol: MQTT QoS1    Host: iot.eclipse.org:1883     Bandwidth: 1000mbps
1 MQTT client, 10 iteration every 10 sec.
```

The results of PUBLISH DELAY for MQTT protocol with QoS1 is presented in Fig. 32, Fig. 33.

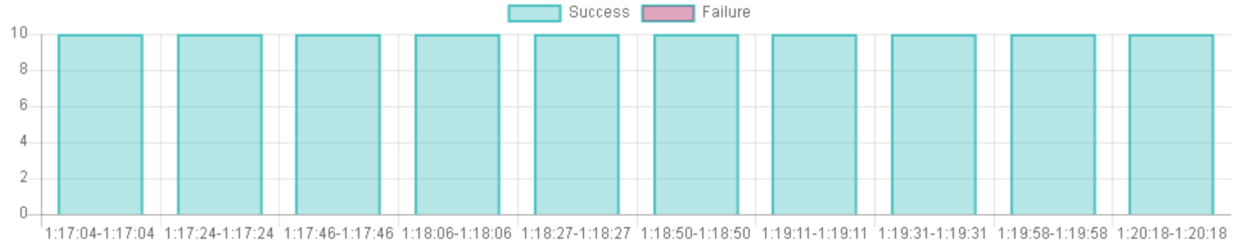


Fig. 32. Simulation results MQTT QoS1: message sending performance for iteration

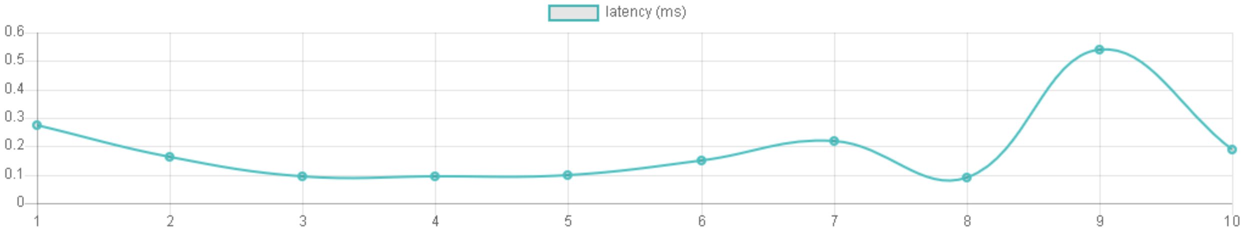


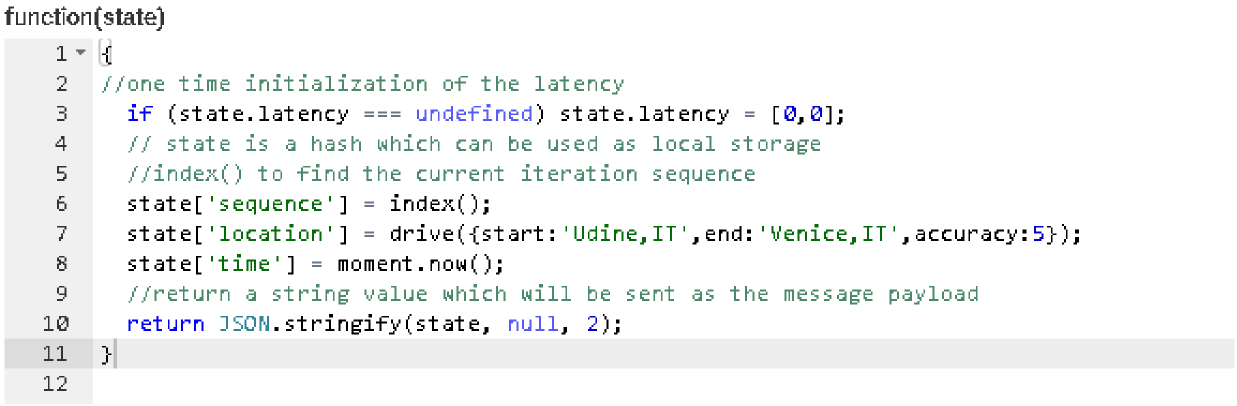
Fig. 33. Simulation results: MQTT publish delay with QoS1 (data numbers)

We can see that MQTT publish delay with QoS1 does not exceed 0.6 ms.

2) *MQTT Publish delay simulation of car GPS sensor data with QoS0.*

In the previous simulation, the sequence of integer number was used like a data sending in the message from the device. In this simulation the data about vehicle position, velocity and precise time was used for sending to the MQTT Broker.

Car GPS sensor template describes the message for publishing in IoT. It is shown in Fig. 34. It simulates the real road condition car driving coordinates and speed data when drive from Udine to Venice. But it is well known, that GPS sensor is a common bur not precise sensor and it has a lot of issues like latency and Doppler errors, so we also simulated the GPS errors like accuracy +-5 meters. Also GPS sensor message for publish contains precise time with enhances accuracy.



```
function(state)
{
//one time initialization of the latency
  if (state.latency === undefined) state.latency = [0,0];
  // state is a hash which can be used as local storage
  //index() to find the current iteration sequence
  state['sequence'] = index();
  state['location'] = drive({start:'Udine,IT',end:'Venice,IT',accuracy:5});
  state['time'] = moment.now();
  //return a string value which will be sent as the message payload
  return JSON.stringify(state, null, 2);
}

```

Fig. 34. Car GPS sensor template

The JSON format was used to send data to the MQTT broker in IoT Cloud web service. It was chosen for this test case because of some enhances comparing to the XML format.

```
{
    Message ID:     //number of the message, integer
    latitude:    // decimal
    longitude:   // decimal
    speed :     // meter per second
    accuracy:     // meter radius
    time:      //precise time
}
```

The simulated data about the car GPS position from Udine to Venice is presented in Table 3:

client	Iteration	latency_time, ms	location_longitude	location_latitude	location_accuracy	speed
0	1	1.85867300	13.234397	46.071105	3	9
0	2	0.46360400	13.232141	46.070934	3	9
0	3	0.82573400	13.23056	46.070901	4	9
0	4	0.31097700	13.229979	46.070832	2	9
0	5	0.33132900	13.228877	46.070494	3	8

	Average	0.75806340				

Table 3. Simulated car GPS data for transmission to the IoT Broker and publish latency for MQTT QoS0

The simulation results for MQTT PUBLISH DELAY for car GPS receiver with QoS0 is presented in Fig. 35, Fig. 36.

Simulation parameters:

```
Protocol: MQTT Host: iot.eclipse.org:1883     Bandwidth: 1000mbps
1 MQTT client,  5 iteration every 10 sec.
```

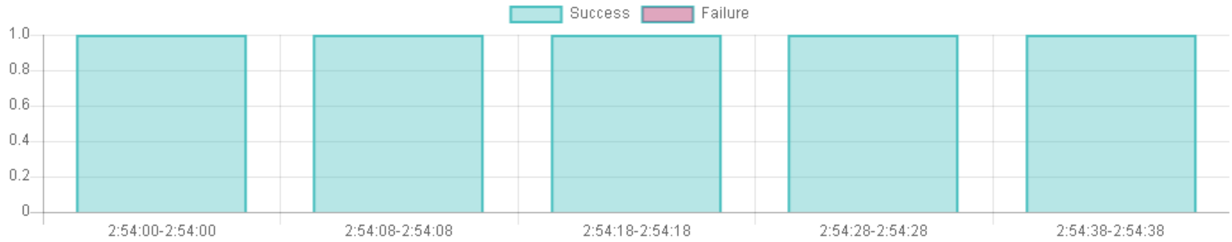


Fig. 35. Simulation results MQTT QoS0: message sending performance for iteration

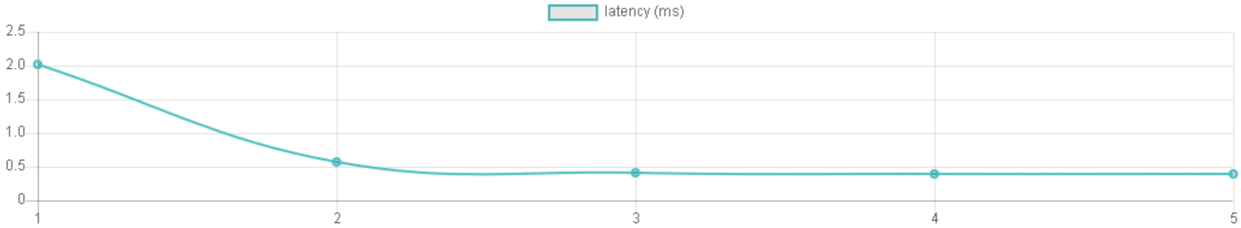


Fig. 36. Simulation results MQTT QoS0: publish delay for car GPS receiver data

We can see that MQTT publish latency with QoS0 for GPS data does not exceed 2.0 ms. An average MQTT publish latency is 0.8 ms.

3) *MQTT Publish delay simulation of car GPS sensor data with QoS 1*

In this simulation the data about vehicle position, velocity and precise time was sending to the MQTT Broker (*t, x,y,v*). The same JSON format was used for sending to the Broker like in previous test. The simulated data about the car GPS position from Udine to Venice is presented in Table 4:

client	Iteration	latency_time, ms	location_longitude	location_latitude	location_ accuracy	speed
0	1	162.2614870	13.234429	46.071117	3	9
0	2	159.7174780	13.232129	46.070983	3	9
0	3	160.4864620	13.230488	46.0709	2	9
0	4	160.4977900	13.229959	46.070817	4	9
0	5	162.3667940	13.228945	46.070492	3	8
	Average	161.0660022				

Table 4. Simulated car GPS data for IoT transmission and publish latency for MQTT QoS1

The simulation results for MQTT PUBLISH DELAY for car GPS receiver with QoS1 is presented in Fig. 37, Fig. 38.

Simulation parameters:

```
Protocol: MQTT Host: iot.eclipse.org:1883    Bandwidth: 1000mbps
1 MQTT client,  5 iteration every 10 sec.
```

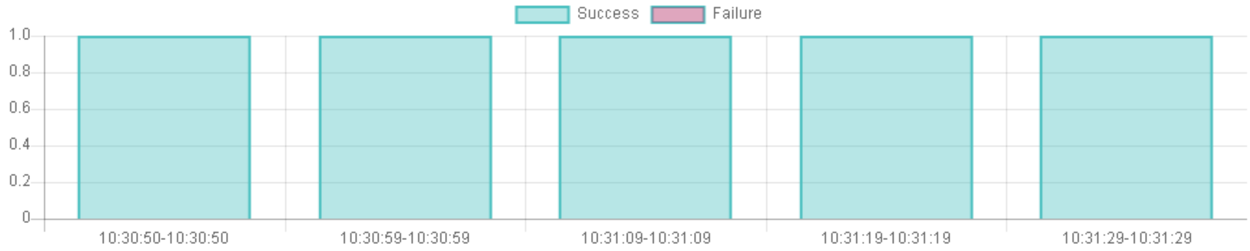


Fig. 37. Simulation results MQTT QoS1: message sending performance for iteration

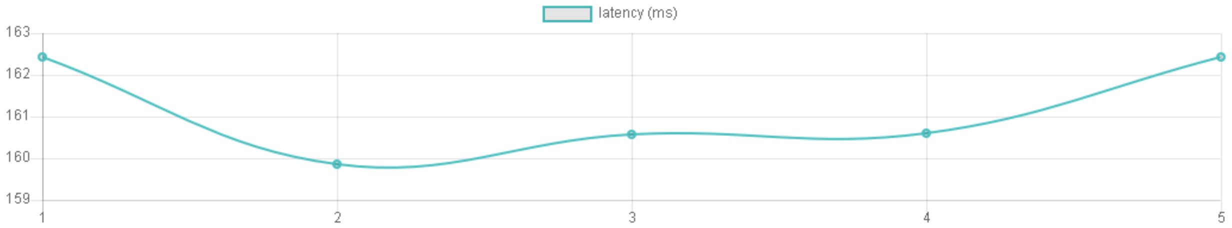


Fig. 38. Simulation results MQTT QoS1: publish latency for car GPS receiver data (ms)

We can see that MQTT publish latency with QoS1 for GPS data does not exceed 163 ms. The average MQTT QoS1 publish latency is 161 ms.

4) MQTT Publish delay simulation of car GPS sensor data with QoS 2

In this simulation the data about vehicle position, velocity and precise time was sending to the MQTT Broker (*t, x,y,v*). The same JSON format was used for sending to the Broker like in previous tests. The simulated data about the car GPS position from Udine to Venice is presented in Table 5:

Client	Iteration	latency_time, ms	location_longitude	location_latitude	location_ accuracy	Speed
0	1	325.69961400	13.234456	46.071092	2	9
0	2	322.46056500	13.23216	46.070943	2	9
0	3	320.55806400	13.23051	46.07091	0	9
0	4	695.47558900	13.229967	46.070849	1	9
0	5	320.04611700	13.228886	46.070512	4	8
	Average	396.84798980				

Table 5. Simulated car GPS data for IoT transmission and publish latency for MQTT QoS2

The simulation results for MQTT PUBLISH DELAY for car GPS receiver with QoS2 is presented in Fig. 39, Fig. 40.

Simulation parameters:

```
Protocol: MQTT Host: iot.eclipse.org:1883    Bandwidth: 1000mbps
1 MQTT client, 5 iteration every 10 sec.
```

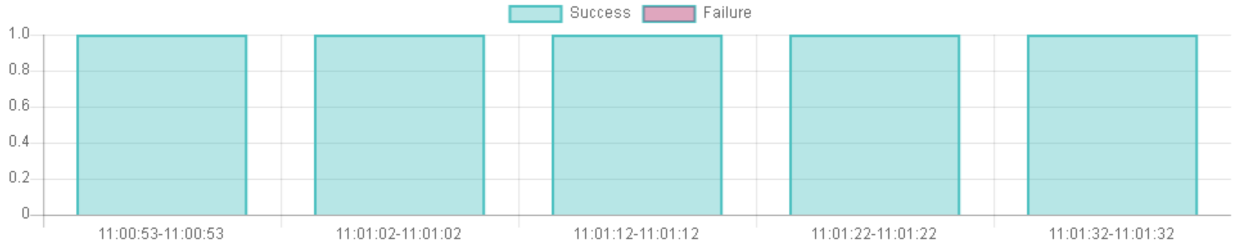


Fig. 39. Simulation results MQTT QoS2: message sending performance for iteration

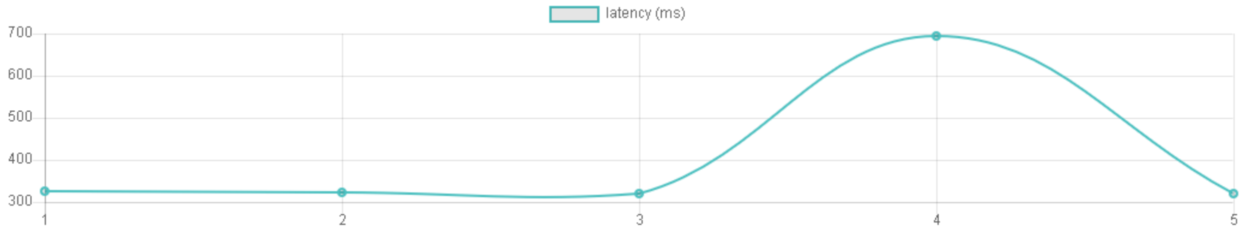


Fig. 40. Simulation results MQTT QoS2: publish latency for car GPS receiver data (ms)

We can see that MQTT publish latency with QoS2 for GPS data does not exceed 700 ms. The average MQTT QoS1 publish latency is 397ms.

5) *Comparative analysis of MQTT Publish delay simulation for car GPS sensor data with different QoS levels.*

In Fig. 41 is shown the MQTT publish latency for different QoS levels for comparison. The compared MQTT publish delay is shown in We can see that MQTT publish latency with QoS2 for GPS data does not exceed 700 ms. The average MQTT QoS1 publish latency is 397ms.

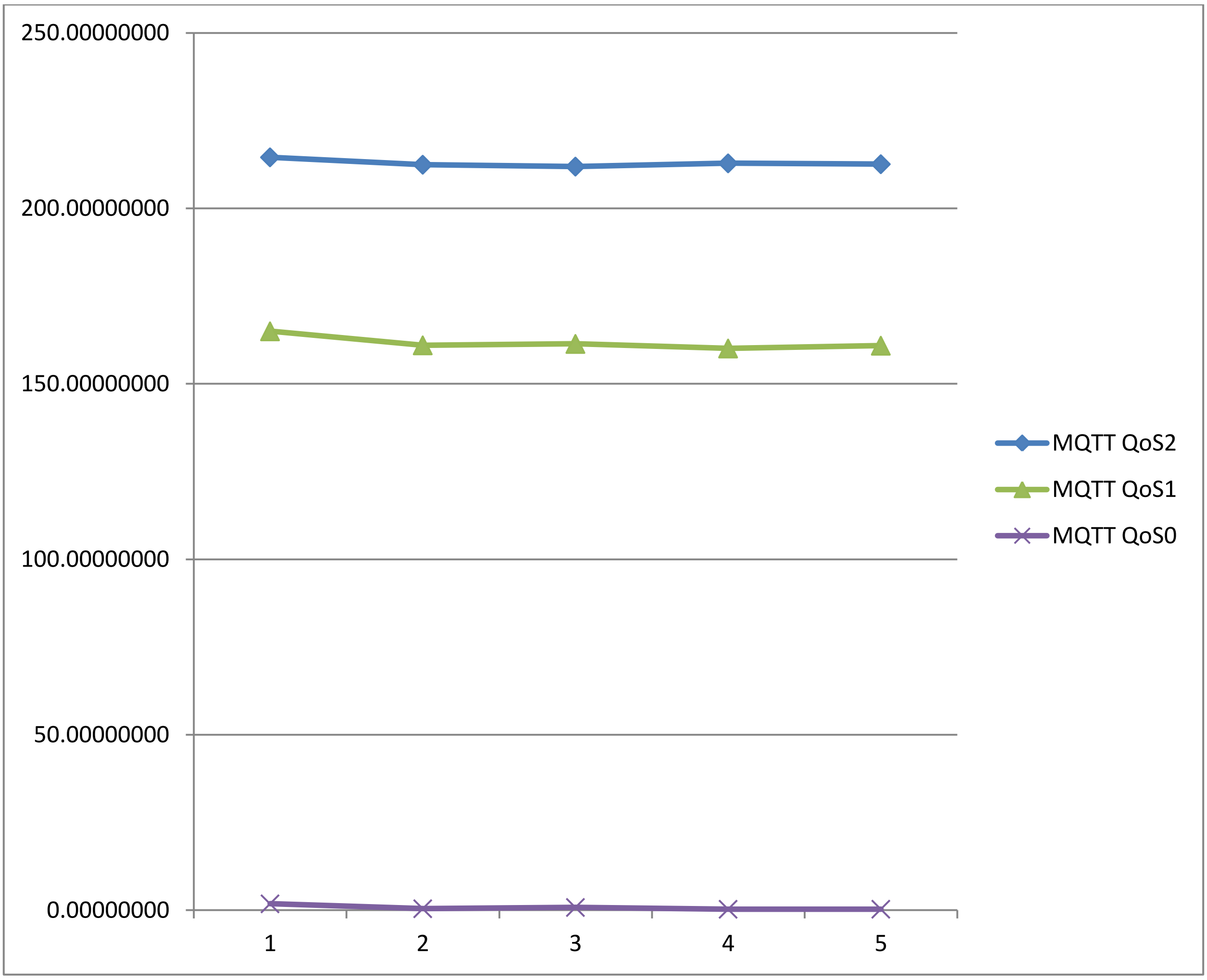


Fig. 41. Simulation results for publish latency of GPS data over MQTT with different QoS levels.

10.1.3.1.1.5.2. MQTT Publish-Subscribe Latency

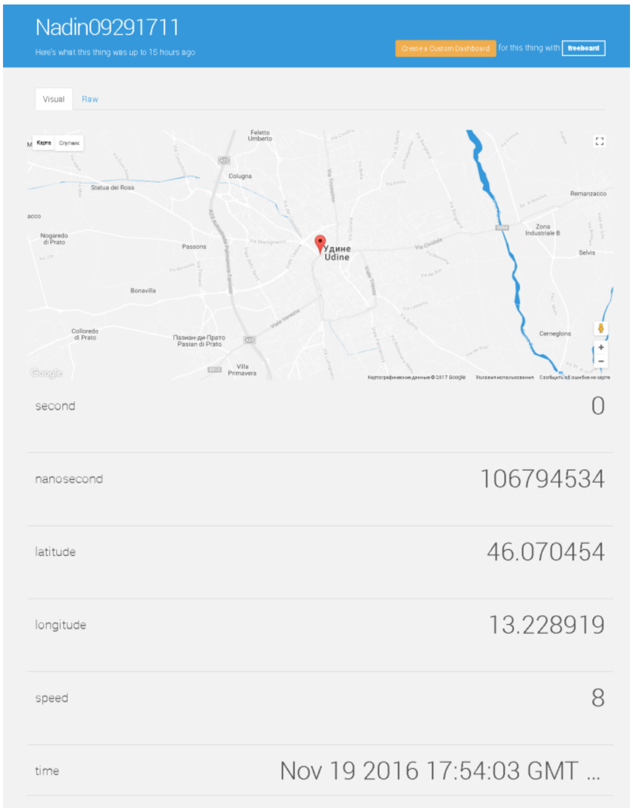
In the simulations below, the IoT delay cause by MQTT Broker, as well as subscription delay on the root from Broker to the subscribers was taken into account.

1) *<u>MQTT PUBLISH-SUBSCRIBE delay simulation with QoS0</u>*

In this simulation the data about vehicle position, velocity and precise time was sending to the MQTT Broker (*t, x,y,v*) and then published on the “chat” for the IoT devices dweet.io, from that it will catch by subscribers with get() method. The same JSON format was used for sending to the Broker like in previous tests. The simulated data about the car GPS position from Udine to Venice is presented in Table 6, Fig. 42.

client	iteration	latency_time, ms	location_longitude	location_latitude	location_accuracy	speed	publish-subscribe latency, ms
0	1	1.62089600	13.23443	46.07109	0	9	0
0	2	0.33763400	13.232135	46.070985	3	9	117.359109
0	3	0.42218700	13.23051	46.07091	0	9	123.749691
0	4	0.22251200	13.229991	46.070624	3	9	222.247425
0	5	0.19727800	13.228919	46.070454	3	8	106.794534
	average	0.56010140					142.5376898

Table 6. Simulated car GPS data for IoT transmission and publish latency for MQTT QoS0



Nadin09291711

Here's what this thing was up to 15 hours ago

for this thing with

second	0
nanosecond	106794534
latitude	46.070454
longitude	13.228919
speed	8
time	Nov 19 2016 17:54:03 GMT ...

Fig. 42. Representation of simulation results for publish-subscribe latency of GPS data over MQTT QoS0.

The simulation results of PUBLISH-SUBSCRIBE DELAY for MQTT protocol with QoS0 is presented in Fig. 43, Fig. 44.

Simulation parameters:

```
Protocol: MQTT Host: iot.eclipse.org:1883    Bandwidth: 1000mbps
1 MQTT client, 5 iteration every 10 sec.
```

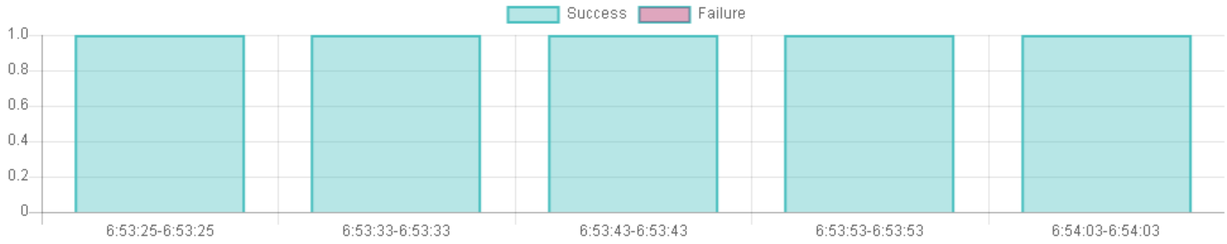


Fig. 43. Simulation results publish-subscription MQTT QoS0: message sending performance for iteration

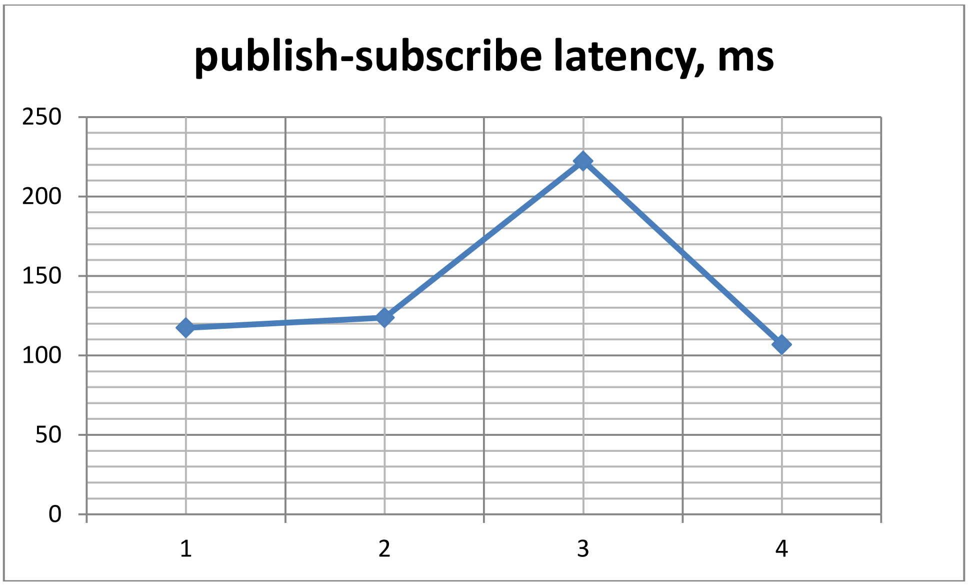


Fig. 44. Simulation results MQTT QoS0: publish-subscribe latency for car GPS receiver data (ms)

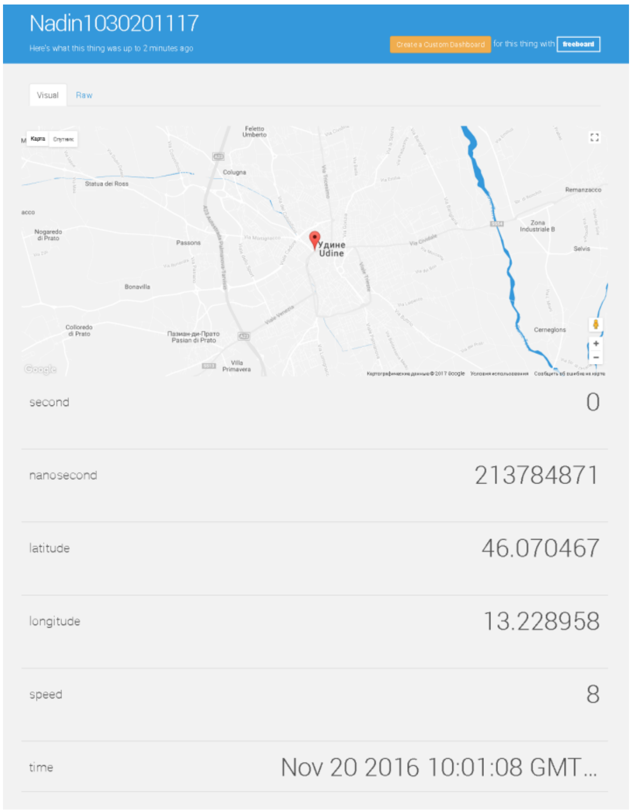
We can see that MQTT publish-subscribe latency with QoS0 for GPS data does not exceed 250 ms. The average MQTT QoS0 publish-subscribe latency is 143 ms.

2) *MQTT PUBLISH-SUBSCRIBE delay simulation with QoS1*

The simulation is the same, but with QoS level 1. The simulated car GPS position and velocity is presented in Table 7, Fig. 45:

client	Iteration	latency_time, ms	location_longitude	location_latitude	location_accuracy	speed	publish-subscribe latency, ms
0	1	213.95589000	13.234455	46.071085	2	9	0
0	2	581.44214300	13.232192	46.070939	4	9	215.132146
0	3	211.61697800	13.230504	46.070902	1	9	211.744441
0	4	530.01447400	13.230015	46.070839	3	9	352.179919
0	5	212.35234900	13.228958	46.070467	4	8	213.784871
	Average	349.87636680					248.2103443

Table 7. Simulated car GPS data for IoT transmission and publish latency for MQTT QoS1



Nadin1030201117

Here's what this thing was up to 2 minutes ago

second 0

nanosecond 213784871

latitude 46.070467

longitude 13.228958

speed 8

time Nov 20 2016 10:01:08 GMT...

Fig. 45. Representation of simulation results for publish-subscribe latency of GPS data over MQTT QoS1

The simulation results of PUBLISH-SUBSCRIBE DELAY for MQTT protocol with QoS1 is presented in Fig. 46, Fig. 47.

Simulation parameters:

```
Protocol: MQTT Host: iot.eclipse.org:1883     Bandwidth: 1000mbps
1 MQTT client, 5 iteration every 10 sec.
```

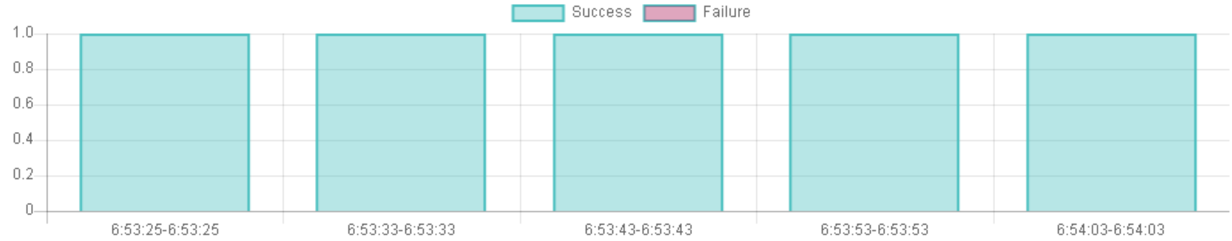


Fig. 46. Simulation results publish-subscription MQTT QoS1: message sending performance for iteration

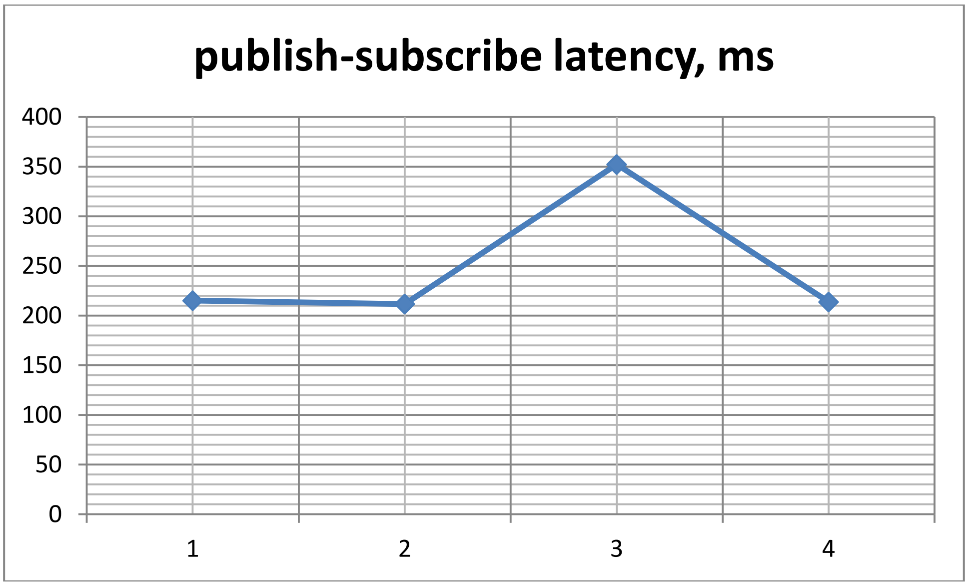


Fig. 47. Simulation results MQTT QoS1: publish-subscribe latency for car GPS receiver data (ms)

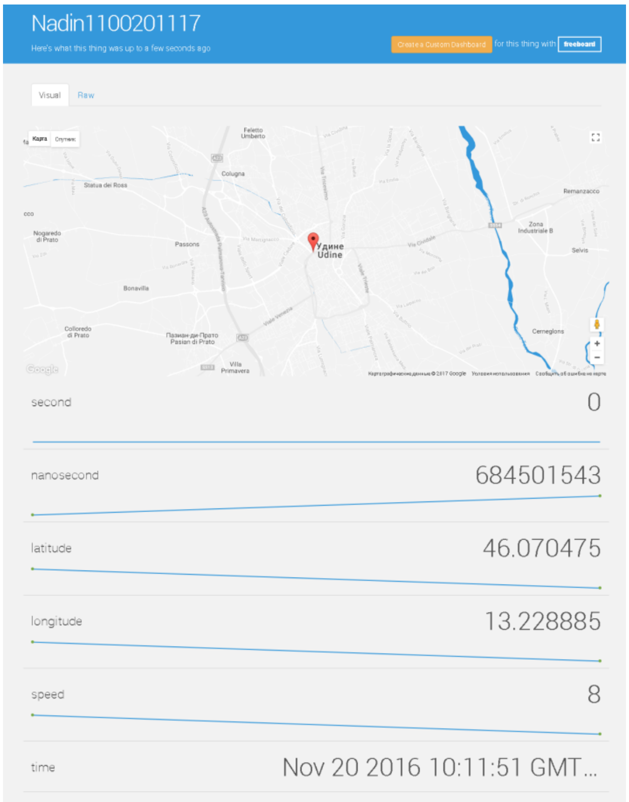
We can see that MQTT publish-subscribe latency with QoS1 for GPS data does not exceed 352 ms. The average MQTT QoS0 publish-subscribe latency is 248 ms.

3) *MQTT PUBLISH-SUBSCRIBE delay simulation with QoS2*

The simulation is the same, but with QoS level 2. The simulated car GPS position and velocity is presented in Table 8, Fig. 48:

client	**iteration**	**latency_time, ms**	**location_longitude**	**location_latitude**	**location_accuracy**	**speed**	**publish-subscribe latency, ms**
0	1	107.82379400	13.234456	46.071068	2	9	0
0	2	106.98954700	13.23215	46.07096	0	9	360.519831
0	3	208.27852300	13.230471	46.070909	3	9	671.320232
0	4	106.03652600	13.230017	46.070842	3	9	351.950068
0	5	208.55164200	13.228885	46.070475	2	8	684.501543
	average	147.53600640					517.0729185

Table 8. Simulated car GPS data for IoT transmission and publish latency for MQTT QoS2



Nadin1100201117

Here's what this thing was up to a few seconds ago

second 0

nanosecond 684501543

latitude 46.070475

longitude 13.228885

speed 8

time Nov 20 2016 10:11:51 GMT...

Fig. 48. Representation of simulation results for publish-subscribe latency of GPS data over MQTT QoS2.

The simulation results of PUBLISH-SUBSCRIBE DELAY for MQTT protocol with QoS2 is presented in Fig. 49, Fig. 50.

Simulation parameters:

```
Protocol: MQTT  Host: iot.eclipse.org:1883     Bandwidth: 1000mbps
1 MQTT client,  5 iteration every 10 sec.
```

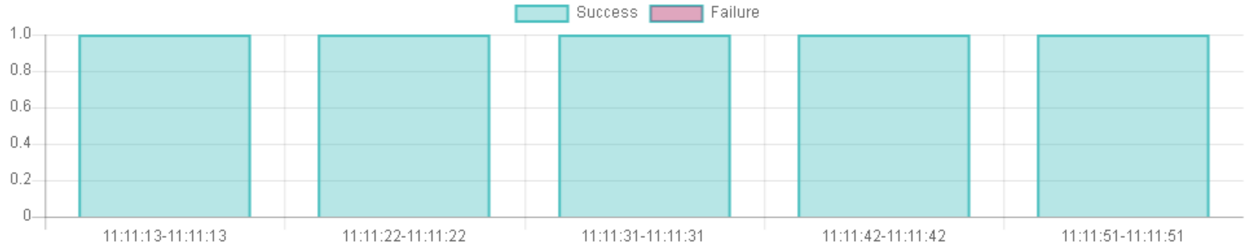


Fig. 49. Simulation results publish-subscription MQTT QoS2: message sending performance for iteration

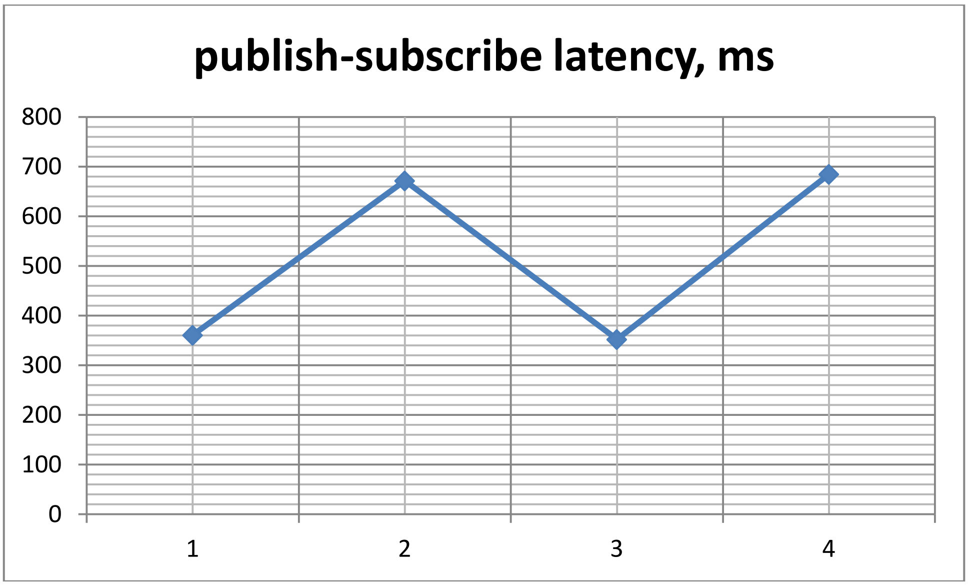


Fig. 50. Simulation results MQTT QoS2: publish-subscribe latency for car GPS receiver data (ms)

We can see that MQTT publish-subscribe latency with QoS2 for GPS data does not exceed 700 ms. The average MQTT QoS2 publish-subscribe latency is 517 ms.

4) *Comparative analysis of MQTT Publish Subscribe delay simulation for car GPS sensor data with different QoS levels.*

In Fig. 51 is shown the MQTT publish-subscribe latency for different QoS levels for comparison. We can see, that MQTT publish-subscribe latency with different QoS levels for GPS data is from 100 to 700 ms.

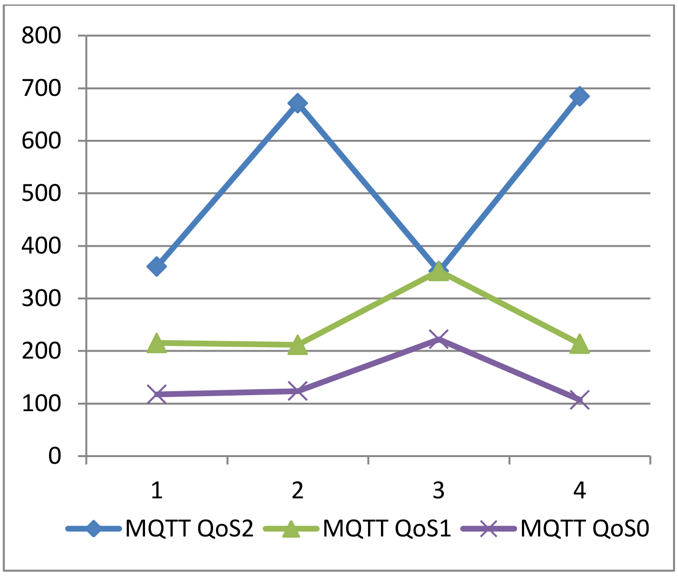
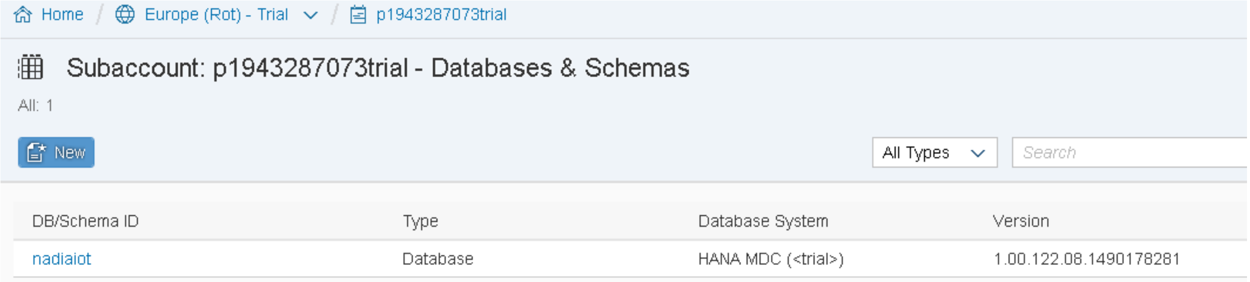


Fig. 51. Simulation results MQTT different QoS: publish-subscribe latency for car GPS data (ms)

8.1.1.1.1.7. IoT Cloud platform DBMS

An instance of NoSQL DB SAP HANA was created in the Cloud computing platform Fig. 52. The data from simulated GPS sensors is sending to the DB Instance of IoT service. HANA is very flexible and allows to work with DB throw SQL and WIPE request (Fig. 53).

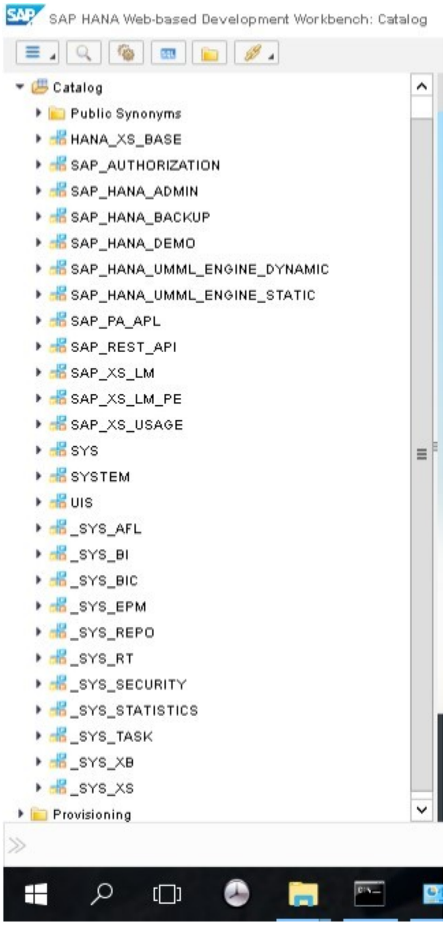


Subaccount: p1943287073trial - Databases & Schemas

All: 1

DB/Schema ID	Type	Database System	Version
nadiaiot	Database	HANA MDC (<trial>)	1.00.122.08.1490178281

Fig. 52. Instance new-SQL DB Hana (SAP)



SAP HANA Web-based Development Workbench: Catalog

- Catalog
  - Public Synonyms
  - HANA_XS_BASE
  - SAP_AUTHORIZATION
  - SAP_HANA_ADMIN
  - SAP_HANA_BACKUP
  - SAP_HANA_DEMO
  - SAP_HANA_UMML_ENGINE_DYNAMIC
  - SAP_HANA_UMML_ENGINE_STATIC
  - SAP_PA_APL
  - SAP_REST_API
  - SAP_XS_LM
  - SAP_XS_LM_PE
  - SAP_XS_USAGE
  - SYS
  - SYSTEM
  - UIS
  - _SYS_AFL
  - _SYS_BI
  - _SYS_BIC
  - _SYS_EPM
  - _SYS_REPO
  - _SYS_RT
  - _SYS_SECURITY
  - _SYS_STATISTICS
  - _SYS_TASK
  - _SYS_XB
  - _SYS_XS
- Provisioning

Fig. 53. Catalog of SAP Hana Instance.

8.1.1.1.1.8. Overall communication time

As we see, the beacon and alert message are very small and their transfer time is split millisecond and thus can be ignored:

$$t_{LTEtransm} = o(t_{comm}) \approx 0$$

Therefore, t_{comm} is consider like average ping response time over LTE from car`s GPS to IoT service and MQTT publish latency with QoS0. Moreover, the subscribe latency was taken into account to provide more precise evaluation (average MQTT publish-subscribe latency with QoS0):

$$t_{comm} \approx t_{IoT\ SR} + t_{IoT\ prot\ delay} \approx 50 + 143 = 193\ ms \approx 0.2s$$

The communication time with MQTT QoS1:

$$t_{comm} \approx 50 + 248 = 298\ ms \approx 0.3s$$

The communication time for MQTT QoS2:

$$t_{comm} \approx 50 + 517 = 567\ ms \approx 0.6s$$

8.1.1.1.1.9. Computation time

For test case 2.1 with infrastructure camera ***computing time*** is:

$$t_{comp} = t_{coll\ predict}$$

Where $t_{coll\ predict}$ – execution time of collision prediction algorithm on the side of the IoT cloud;

8.1.1.1.1.10. Execution time for collision prediction algorithm

The collision prediction algorithm is a server side application and is running in the instances of the IoT service Cloud Datacenter. We take into account that calculation should be provides for any pair of pedestrian and car in the some common city conditions. The experiment results from the paper [28] estimates the execution time of collision prediction algorithm.

$$t_{comp} = 500\ ms$$

The experiments in [28] were provided on the prototype servlet on Amazon Web Service (AWS) Elastic Compute Cloud (EC2) C4.8xLarge instance.

The collision avoidance algorithm is parallelized; it is running for the any pair car-pedestrian in their own thread. The sensor`s data are randomly generated on the server-side app/ This testing data including position, speed and heading of vehicle/pedestrian.

8.1.1.1.1.11. Results for processing time

The MQTT with QoS1 has optimum quality. So, result processing time for the test case 1.1 is:

$$t_{process} = t_{comm} + t_{comp} = 500\ ms + 298\ ms \approx 0.8s$$

8.1.3.2. Test case 1.2. Parked car collision avoidance Architecture with car GPS and parking lot camera

In this section we propose a collision avoidance architecture for parked cars based on the same principle with SiDAS solution. It is an approach for parched car collision avoidance subsystem based on both data in-vehicle systems and sensors and infrastructure systems and sensors via IoT. The architecture is presented in the Fig. 54. We are increasing situation awareness via the fusion solution taking into account the information from car GPS and infrastructure camera.

Car camera does not able to detect the departing car because of it would hide in other parking car (or it might be some other object, like an angle of some building). However, the departing car can be detected by infrastructure camera. The data fusion from car GPS and infrastructure camera via V2X communication and IoT helps to alert the drivers.

The first car position (x_{car1}, y_{car1}) and second car position (x_{car2}, y_{car2}) are beaconing to the IoT cloud database. We suppose that there are a GPS receiver and a camera inside the moving car and there is an infrastructure camera on the street near the parking lot.

The same with scenario 1, we suppose, that driver connect car sensors camera and GPS to the IoT services. The infrastructure camera is the part of the ITS system. The ITS, in turn, is connected throw getaway to the Street Camera IoT service. The data about moving car position are beaconing by the Car GPS IoT-service with the frequency which depends on the car speed and pot (normally, every 1 second). The parking car is not visible for the car driver moving on the street, but it is visible for the street camera. A moving car activity detection algorithm is working for infrastructure camera and detect the moving and starting car and send the notification to the both cars.

The video streams from infrastructure cameras as well as GPS beaconing position of the car moving on the street are sending to the IoT services. Then moving car detection algorithms detect the car and its coordinated by the video of infrastructure camera. After that, probability of collision (collision index) is calculated. In the case of high collision risk warning message is sent to the driver`s Smartphone/Tablet.

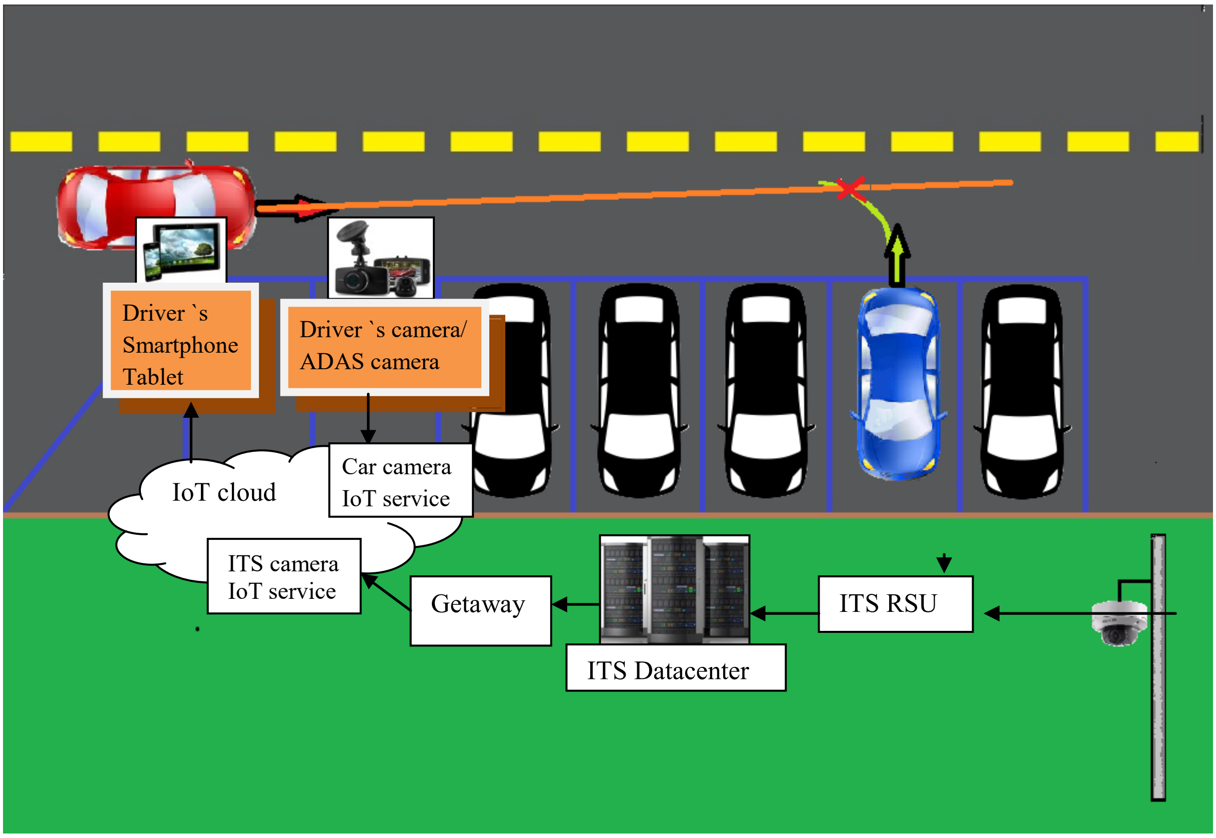


Fig. 54. An architecture of parking car collision avoidance using car GPS and infrastructure camera

The same with first test case, according to the SiDAS technical requirements in data acquisition and processing, NoSQL DB SAP HANA hosted on Cloud Platform DC is chosen. The Cloud Data Center (CDC) provides scalable and distributed data store and extremely powerful processing of huge amounts of data.

In this test case is used both structured GPS data and unstructured video data. For this case, I suggest to use same in-memory smart data streaming of DBMS HANA for structured GPS data. But for non-structured video data my practical experience teaches me to use Hadoop, and then connect it with SAP HANA using Hana Vora instruments. I suggest following structure (Fig. 55):

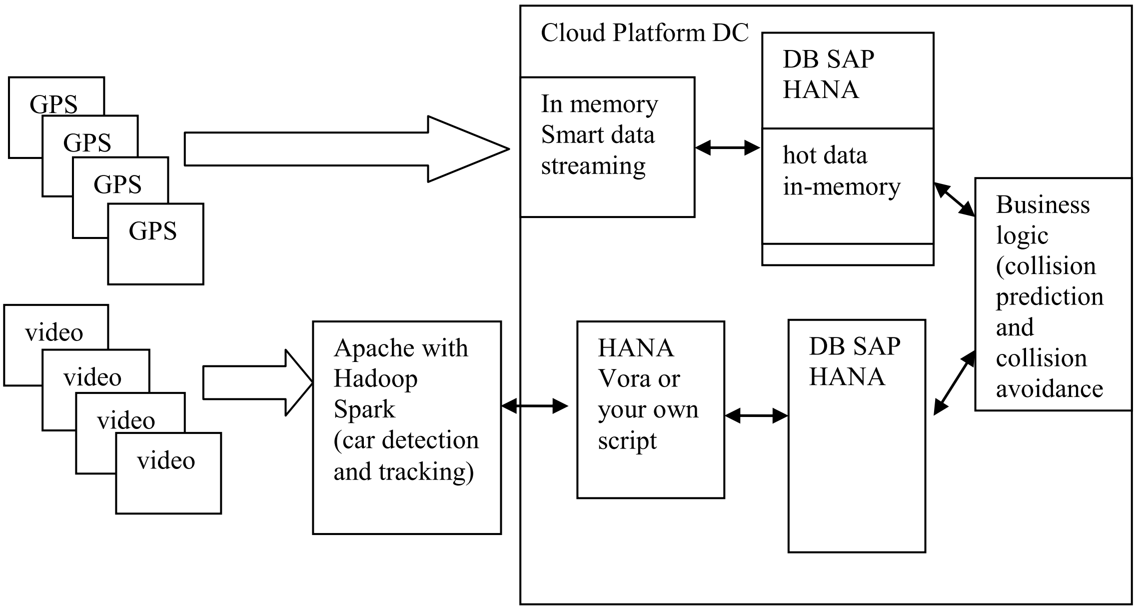


Fig. 55. DB Data transmission structure for structured data (GPS) and unstructured data (video).

SAP HANA and Hadoop data store provide Big Data processing for real-time collision avoidance.

The collision risk and margin time is calculated based on the same approach with the collision avoidance algorithm for the first test case.

8.2. Case Study 2: Pedestrian collision avoidance system based on IoT

Between the all road users, pedestrians and cyclists are more vulnerable; they also referred to as Vulnerable Road Users (VRU). Pedestrian safety analysis has chosen because of the safety of the VRU is a most important issue. The accidents involving VRU cause the largest share of the people death on the road. Worldwide 49% of all road traffic deaths are VRU. That is more than 0.5 million of people every year [93]. Pedestrian safety algorithm is investigated like a case study for proposed SiDAS architecture approach. Like a case study is considered pedestrian safety IoT service.

A lot of efforts have been made to improve pedestrian safety in the transportation systems. In-vehicle pedestrian detection based on machine vision is a most common approach. Many collision avoidance systems use pedestrian detection and their position extraction by in-vehicle sensors like GPS, INS, front and rear view cameras, Lidars.

In-vehicle sensors data can help to ensure the safety of visible pedestrians from the vehicle, that is “in Line-of-Sight” (LOS). But they not effective for not visible pedestrians from the vehicle – “non in Line-of-Sight” (NLOS). NLOS pedestrian can be in obstructed visibility, bad weather conditions or during the night time. A set of the recent studies are towards to safety of NLOS pedestrians.

In this section the novel approach for a V2X pedestrian collision avoidance system is proposed. We propose to increase the visual situational awareness of road users by IoT technology. The proposed system intends to reduce the collision risks by taking into account available systems and common available driver`s and pedestrian`s devices and gadgets. The data fusion from sensors, gadgets and infrastructure systems improves safety in obstructed visibility and bad weather conditions.

In this section is presented in more detail architecture framework for the IoT pedestrian service like a part of the SiDAS. Also, here is proposed our idea of the architecture of pedestrian collision avoidance system. We propose a variant of a collision avoidance architecture in NLOS

Conditions over IoT like a case study for flexible IoT Architecture Framework [82], [84]. We have a similar view with the Cloud based Cyber Physical framework (C2PS) [94].

Moreover, it is proposed the novel collision avoidance algorithm and is considered timing analysis of the collision situation. As an example the collision scenarios involving pedestrians are presented. Also analysis of the safety enhances is providing. In the research key parameters affecting the safety is investigated. For example, the warning time margin between warning moment and possible collision time is analysing. For that, kinematic models of pedestrians and cars are considering.

8.2.1. Collision scenario 2

Let consider the common collision scenario (Fig. 56), than the pedestrian is approaching to an uncontrolled pedestrian crossing and going to cross the road. Pedestrian is not visible for the driver because of parking cars or building angle and pedestrian does not able to see the car.

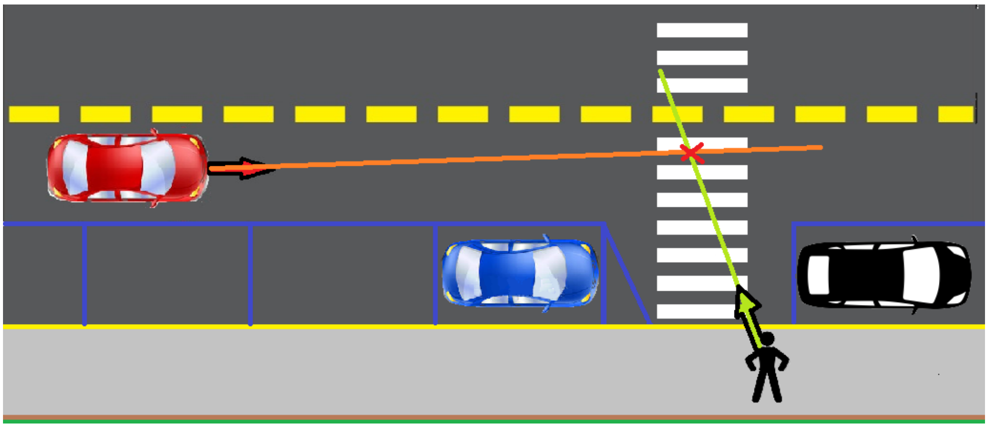


Fig. 56. Collision scenario for car and pedestrian in NLOS conditions

8.2.2. Overview of solutions for pedestrian safety

Vehicle networks provide for collision avoidance algorithms [7]. But the classic ITS and VANET structure requires the installation of the vehicle modules (VS) in the car [23]. The more detail architecture of vehicle systems was considered in the previous sections. Another problem, that most of these systems are aimed at the inter-vehicle collisions avoidance using V2V and V2I communication [7]. Only a few of them take into account VRU. For example, in the paper [26] the cooperative system of VRU safety is presented. This system uses in-vehicle sensor (near infrared (NIR) camera) and V2P communications. But the system requires high cost camera and installation of the Vehicle Station and the Pedestrian Station.

In the paper [29] V2P and P2V communication is considered for the collision avoidance between cars and pedestrians. Pedestrian`s Smartphone is used for pedestrian position beaconing, but it requires a vehicle module in order to broadcast the vehicle position.

There are also some alternative solutions. For example, in the paper [95] an automotive socio-cyber-physical system is presented. It consists of Smartphone (information space with social context aware information); driver (social and physical space); vehicular (physical space); Cloud (information space). The system warns the driver about dangerous events: drowsiness state of the driver, driver distraction, tailgating and lane weaving. But this system uses only Smartphone and inefficient in NLOS conditions.

In the paper [28] is proposed the approach using Smartphone for energy safe position beaconing in driver of pedestrian mode and collision avoidance app in Cloud DataCenter. This system is appropriate for NLOS conditions and do not need extra equipment, but it take into account only Smartphone data.

In [96] the authors present a framework of system safety for cyber-physical system (CPS), actually for multi-human-in-the-loop systems.

Sensors for collision avoidance system

Collision avoidance systems usually need to define vehicle and pedestrian positions. The sensors used for vehicle position detection are INS [25], WiFi, GPS, beaconing by Smartphone A-GPS technology [28], camera. In [91] is proposed a INS/GPS time synchronization method. For pedestrian position detection usually is used beaconing by GPS [27], Smartphone A-GPS [28], Lidars [27], INS, car camera [25], infrastructure city camera.

In the paper [97] Lidar and computer vision is used to provide vehicle and pedestrian detection.

Communications for collision avoidance

The classic technologies using for vehicle-to-pedestrian (V2P), vehicle-to-X (V2X) and pedestrian-to-X (P2X) communications are: WAVE (based on IEEE 802.11p), IEEE 802.11g [27], DSRC, ZigBee (based on IEEE 802.15.4). A set of collision avoidance system based on cellular networks was developed. In [33] is considered the communication for collision avoidance over 4G/LTE. Communications for emergency vehicle applications over 5G networks were presented in [92]. Nowadays, IoT is considered like a promising paradigm to improve significantly emerging communications. In particular, IoT enabled us to use data from a wide range of distributed sensors (in-vehicle as well as infrastructure).

Classic architecture for pedestrian collision avoidance

The classic architecture for our test case is presented in the Fig. 57. The vehicle station and pedestrian station are sending their current information and location beaconing to the Road Side Unit (RSU). We should take into account DSRC communication delay for communication between vehicle station (VS), road side unit (RSU) and server side. Since distance between vehicles will be V2V communication will start only when cars close up to communication distance. We should take into account DSRC communication delay for communication between the vehicles.

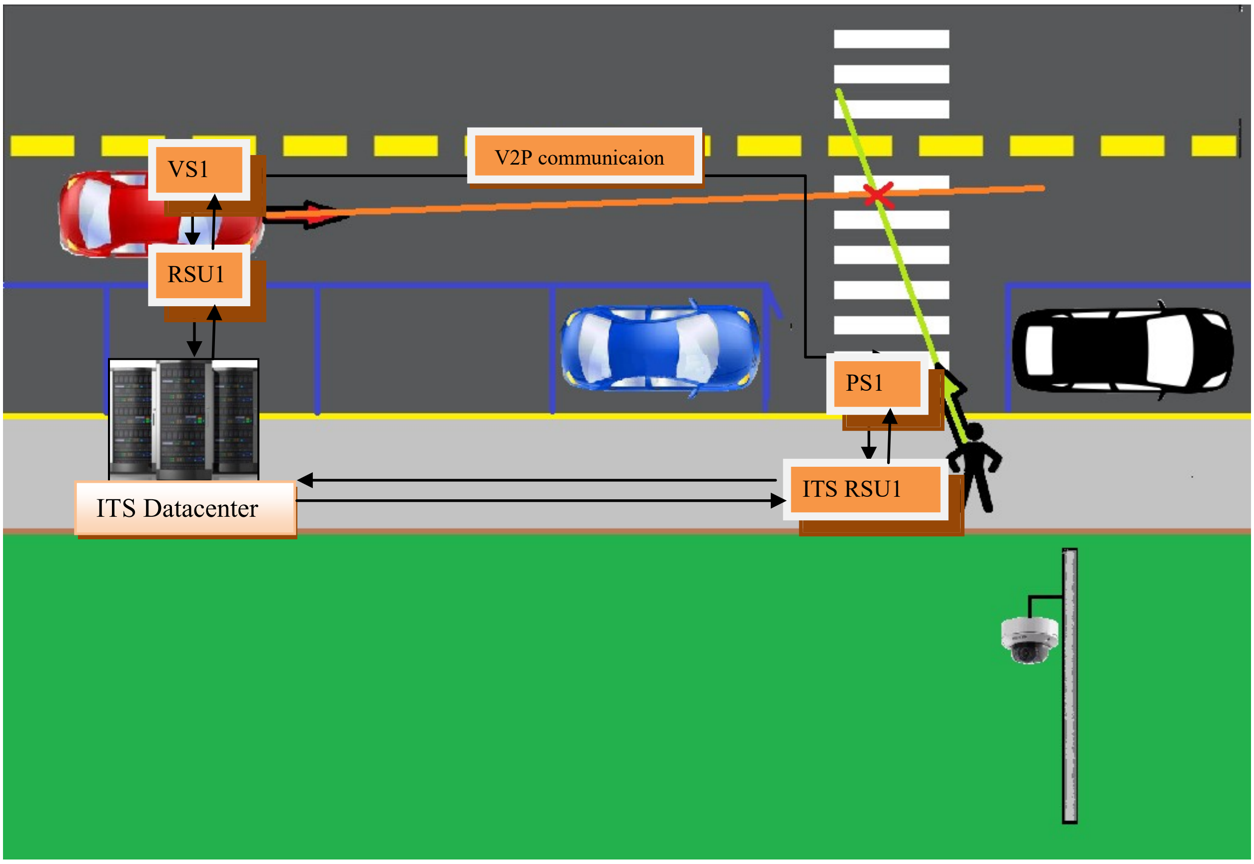


Fig. 57. Classic ITS solution

8.2.3. Proposed SiDAS pedestrian collision avoidance Architecture

8.2.3.1. Test case 2.1. IoT Pedestrian Collision Avoidance Architecture with car GPS and infrastructure camera

We propose an architecture of SiDAS pedestrian collision avoidance subsystem based on both data in-vehicle systems and sensors and infrastructure systems and sensors. It is a one possible variant of a collision avoidance architecture in NLOS Conditions over IoT like a case study for flexible IoT Architecture Framework [28], [82]. Also we have a similar approach with the Cloud based Cyber Physical framework (C2PS).

The architecture is presented in the Fig. 58. As was mentioned before, this work aims at enhancing road safety by increasing driver situational awareness. The purpose is to provide the fusion solution taking into account all the available information: pedestrian detection results and pedestrian position from the infrastructure camera, GPS position and pedestrian detection from in-vehicle sensors and available devices: driver Smartphone and so on.

Car camera does not able to detect the pedestrian because of parking car (or it may be some other object, like building angle). However, the pedestrian can be detect from video of infrastructure camera or location beaconing from the pedestrian`s Smartphone. Therefore, V2X communication and IoT are selected to increase driver situation awareness.

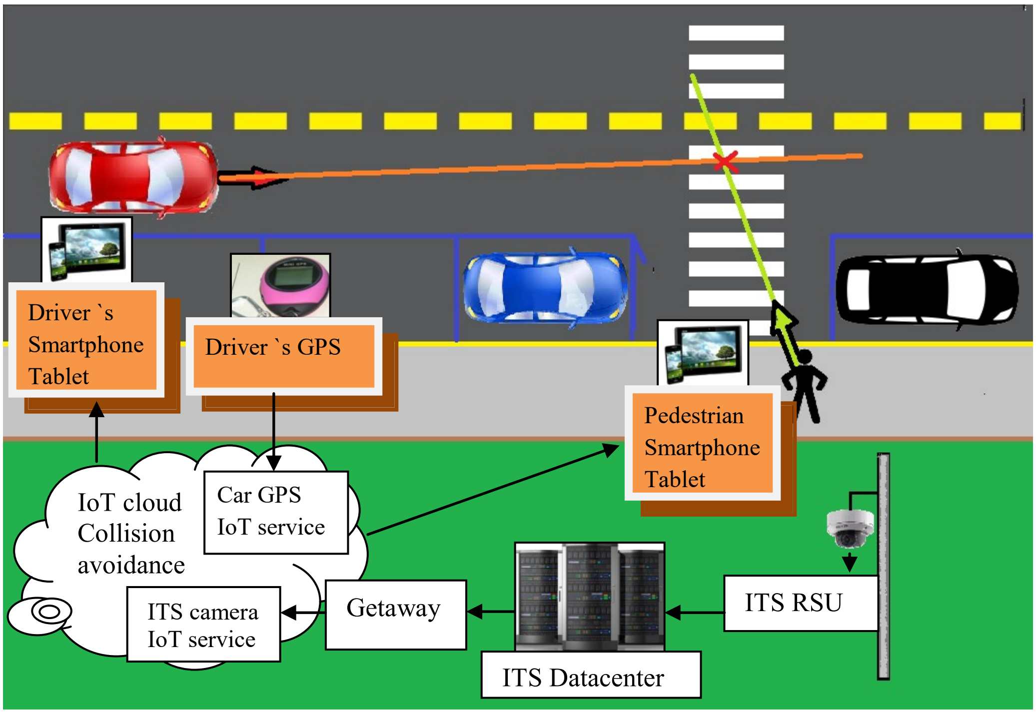


Fig. 58. An architecture of SiDAS pedestrian collision avoidance

First we should to assess the collision risk. Based on that, system will make decision about of driver notification.

8.2.3.1.1. Analysis of the collision time intervals for systems based on IoT

The most important parameters for collision avoidance are a time to collision and time margin, which driver has before to start braking. Moreover, an available time for the calculation and communication should be taking into account for the proposed pedestrian collision avoidance architecture.

That’s why it is important to evaluate a time intervals and time margin, which has a driver, for the collision scenario. Also we should evaluate and take into account the time available for detection of a pedestrian/car, transmission of data using V2X and IoT communications, calculations and warning for the proposed architecture.

In this section we will present a physical analysis of the different time intervals that occur in an accident scenario as shown in **Fig. 56**. The study is focus on the intervals from data acquisition moment until the probable collision moment.

Let suppose that the vehicle is travelling in a straight line (road is a line) with the constant speed $\vec{v}_{car} = const$ and without acceleration $\vec{a}_{car} = 0$, and the vehicle move towards to the probable collision point (x'_{coll}, y'_{coll}) in the GPS coordinates.

In the road coordinate system probable collision point is (x_{coll},0), projection of the vehicle speed on the road axis (V_{car},0).

c) First let consider a case than the ***driver do not aware about the collision risk***, ***pedestrian will be on the road*** (pedestrian velocity v_{ped}=0) in the coordinate (x_{coll}, 0) in time t_{coll} for the car (Fig. 59).

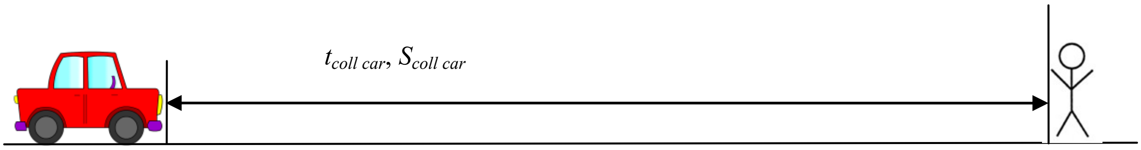


Fig. 59. Time intervals without collision avoidance warning

If we suppose that car motion is a uniform linear motion with acceleration a_{car}=0 (V_{car}=const):

$$t_{coll\ car} = {}^{S_{coll\ car}}\!/_{V_{car}} = {}^{|x_{coll} - x_{car}|}\!/_{V_{car}}$$

where

t_{coll} – is the predicted time frame until the probable collision moment (time to collision), it is the whole time frame in which car will reach the probable collision point (x_{coll}, y_{coll}), time to collision;

$S_{coll\ car}$ – car displacement from the current point to the collision point (= distance in our case of linear motion).

d) If ***driver aware about the probable collision situation***, time model is so (Fig. 60):

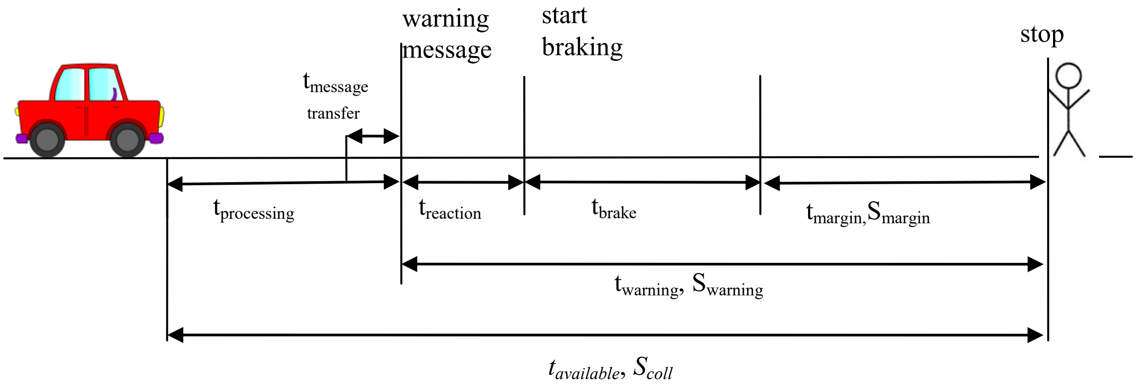


Fig. 60. Time intervals with the collision avoidance warning for $t_{margin}>0$

where:

$t_{available}$ – is the whole time period which system have the avoid collision in the case than the driver have SiDAS, which aware the driver about the dangerous situation. Let note, that $t_{available}$ for aware driver is different from the $t_{collision}$ for unaware driver ($S_{collision}$ is the same).

$t_{processing}$ – is the time for detection of the car position/pedestrian position (time for beaconing), for data transmission to the IoT Cloud, calculations and transmission of the warning message to the driver/pedestrian.

$t_{warning}$ – is the time from warning moment to the collision point.

$t_{reaction}$ – reaction time of the driver and car transmission.

t_{margin} – time margin which system have.

t_{brake} – time to stop with maximum brake force.

8.1.1.1.1.12. Processing time

Let consider the processing time

$$t_{process} = t_{comm} + t_{comp},$$

where t_{comm} is the communication time for transmitting the beacon message about car position to cloud server and the collision alert message from cloud to Smartphone,

t_{comp} is the time for computation required to predict a probable collision.

8.1.1.1.1.13. *Communication time for IoT based system*

We propose formula for communication time calculation for IoT based systems taking into account infrastructure and car information like:

$$t_{comm} = max\,\{,t_{Si1\,DT}, \dots, t_{Sin\,DT}, t_{Sc1\,DT}, \dots, t_{Scn\,DT}\} + t_{emerg\,DT}$$

$\{t_{Si1\,DT}, \dots, t_{Sin\,DT}\}$ is the time spent for transmitting data from the infrastructure sensors (S_1,…S_n) to the IoT service;

$\{t_{Sc1\,DT}, \dots, t_{Scn\,DT}\}$ is the time spent for transmitting data from the car sensors (S_1,…S_n) to the IoT service;

We are considered the communication time for the scenario 2.1 like a case study:

$$t_{comm} = max\,\{t_{car\,DT}, t_{\inf\,DT}\} + t_{emerg\,DT}$$

$t_{car\,DT}$ – time spent transmitting the data from the car`s sensors (GPS, camera, DVR) to the IoT cloud

For our test case we suppose that car data is only GPS beaconing and transmission is going over IoT, so,

$$t_{car\,DT} = t_{car\,IoT\,SR} + t_{car\,IoT\,DT}$$

where

$t_{IoT\,SR}$ – is the average ping response time to IoT service. Usually we do not take into account ping response, but in the IoT ping latency can be quite significant because of geographical distance between sensors and remote IoT services. IoT time response is considered below.

$t_{car\,IoT\,DT}$ – time spent transmitting car data in IoT Cloud.

$t_{inf\,DT}$ – time spent transmitting infrastructure data to the IoT. For the scenario 2 ITS server grab video from the street cameras and process it to detect pedestrians. After that, the detection results transmit to the IoT service. So, data transmission consists of time spent transmitting video from infrastructure camera to ITS server and time spent transmitting the pedestrian detection results throw the IoT infrastructure.

$$t_{inf\,DT} = t_{ITS\,DT} + t_{inf\,IoT\,SR} + t_{inf\,IoT\,DT}$$

$t_{ITS\ serv\ transm}$ – time spent transmitting data from infrastructure cameras to the local ITS system (for our test case we suppose ITS system is available).

$t_{emerg\ DTt}$ – the time spent transmitting an emergency driver alert.

For our scenario test case we suppose that driver alert is going over LTE, so,

$t_{emerg\ DTt} = t_{LTE\ transm}$

8.1.1.1.1.14. ITS communication delay

In the case of ITS system is available and video from the infrastructure camera grab to the ITS servers. According to the DSRC/WAVE IEEE 802.11p recommends latency in standard of less 100 ms and research of ITS latency for high priority application [7], we suppose the worse case

$$t_{ITS\ DT} = t_{DSRC} = 100\ ms.$$

8.1.1.1.1.15. LTE communication delay

As it was considered before, LTE transmission time is:

$$t_{LTEtransm} = 1.6 \times 10^{-4}\ s$$

8.1.1.1.1.16. IoT communication delay

Time for IoT communication:

$$t_{IoT\ comm} = t_{IoT\ serv\ resp} + t_{IoTdata\ transm}$$

The response of the IoT service we can suppose equal to a Cloud time response, which according to [28] and [33]

$$t_{IoTserv\ resp} = 50\ ms$$

If in the car the vehicle side station is absent, we suppose LTE data transmission for the car GPS beacon. In that case:

$$t_{IoTtransm} = t_{LTEtransm} + t_{IoT\,prot\,delay}$$

As we see, the beacon and alert message are very small and their transfer time is split millisecond and thus can be ignored:

$$t_{LTEtransm} = 1.6 \times 10^{-4}\,s = o(t_{comm}) \approx 0$$

For MQTT QoS1 average IoT publish-subscribe latency is: $t_{IoT\,prot\,delay} = 298\,ms$

Therefore, t_{comm} is consider like average ping response time over LTE from car`s GPS and infrastructure camera to IoT service and in the worse case it includes t_{DSRC}:

$$t_{comm} \approx t_{IoTserv\,resp} + t_{IoT\,prot\,delay} + t_{DSRC} \approx 50 + 298 + 100\,ms \approx 450\,ms = 0.45s$$

8.1.1.1.1.17. Computation time

For test case 2.1 with infrastructure camera ***computing time*** is:

$$t_{comp} = t_{ped\,detect} + t_{coll\,predict}$$

Where

$t_{ped\,detect}$ – execution time of pedestrian detection algorithm processed on the side of ITS/smart City server;

$t_{coll\,predict}$ – execution time of collision prediction algorithm on the side of the IoT cloud;

Pedestrian detection execution time

In this section the execution time for most common and fast algorithm is presented. A lot of researches use classifier HOG+linear SVM [98]. HOG+SVM has a good results [99]. Moreover, that method used deep architectures have a same results with DPM and DF approaches.

The pedestrian detection algorithm is a server side application and it is processing in the power infrastructure datacenter. Usually it can be datacenter instance in the high speed SAN network architecture). In the worse case infrastructure camera can be connected to the PC and pedestrian detection algorithm can be processed on the virtual “server” upped on the common

PC with common architecture AMD64 (x86-64). Let consider the time in the worst case calculation scenario.

The experiments results for the HOG+SVM on x86-64 are presented in Table 9.

Algorithm	**CPU**	**Assembly**	**Execution time**
HOG+SVM	**Core i7 Q720@1.6Ghz**	libemgucv-windows-x64-2.2.1.1150	760
HOG+SVM	**Core i7 Q720@1.6Ghz**	libemgucv-windows-x64-tbb-ipp-icc--2.2.2.1195	307
HOG+SVM	**Core i5 241OM@2.30GHz**	emgucv-windows-universal 3.0.0.2157	615

Table 9. Pedestrian detection execution time

Execution time for collision prediction algorithm

The collision prediction algorithm is a server side application and is running in the instances of the IoT service Cloud Datacenter. We take into account that calculation should be provides for any pair of pedestrian and car in the some common city conditions. We use the experiment results from the paper [28] to estimate the execution time of collision prediction algorithm.

$$t_{comp} = 500\ ms$$

8.1.1.1.1.18. Result processing Time for test case 2.1

The result processing time for the test case 2.1 is:

$$t_{process} = t_{comm} + t_{comp} = 450ms + 1260ms = 1710ms \approx 1{,}7\ sec$$

8.1.1.1.1.19. Time of reaction

According to the experimental measurements in the studies [100] and we suppose an average reaction time of a driver with $t_{driver\ react}$ = 0.63 sec.

The average response time of the brakes is given with $t_{ransm\ react}$ = 0.2 seconds. These two values added together result in 0.83 seconds on average between the driver warning and the start of the car's braking process.

$$t_{reaction} = 0.83\ s$$

This average value is used in our analysis throughout this research.

8.1.1.1.1.20. Time of braking

Let`s consider the braking time of the car from the speed V until full stop.

For a rough estimate of braking time we can use simple kinematic equation …:

$$t_{brake\ min} = \frac{v_{car}}{a_{brake\ max}}$$

But in fact, the time of braking depends on a set of parameters: weather, road condition, car model etc. As well as the deceleration of the car is not constant ($a_{brake}(t)$) since it takes time to get maximum deceleration ($t_{dec\ rise}$), as well as during rise of deceleration, the brake time will depends on weight of the vehicle. A more precise assessment is given in the road accident investigation [101]:

$$t_{\mathrm{brake}} = 0.5 \cdot \mathrm{t_{dec\ rise}} + \frac{\mathrm{V_0 \cdot K_{ef}}}{\mathrm{g} \cdot \varphi_{\mathrm{x}}} = 0.5 \cdot \varphi_{\mathrm{x}} \cdot \frac{\mathrm{P \cdot (b + \varphi_x \cdot h_c)}}{\mathrm{K_1 \cdot L}} + \frac{\mathrm{V_0 \cdot K_{ef}}}{\mathrm{g} \cdot \varphi_{\mathrm{x}}} \approx \frac{0.5P(1.32 + \varphi h_c)}{30L} + \frac{V_0 \cdot 1.15}{g \cdot \varphi}$$

where V_0 – initial speed of the vehicle,

$t_{dec\ rise}$ – time of rise of deceleration,

φ – the coefficient of adhesion of the road surface (φ_x – projection on the road axle) (≈0.6),

L – the distance between the front wheel and the rear wheel of the vehicle,

P –the car weight,

h_c – the height of the centre of gravity,

b – the distance between centre of gravity and rear wheel,

$$b = \frac{m_1}{m} \cdot L,$$

m_1 – the mass on the front axle of the vehicle, m – whole mass of the vehicle.

K_{ef} – the brake performance rate.

We would calculate brake distance according to other formula which take into account the braking rate:

$$S_{brake} = \frac{v^2}{2 \cdot g \cdot (1 - 0.98 \cdot \ln v) \cdot \varphi}$$

8.1.1.1.1.21. Time intervals analysis for the different available time to collision point

Unfortunately, it is not possible to avoid all dangers situation by the driver warning systems. For example, if pedestrian happens to get on the road one meter before the car on the high speed. In this case

$$t_{available} \leq t_{processing} + t_{reaction} + t_{brake};$$

$$t_{margin} = 0;$$

The list below shows the equations for different values of available time:

1. If $t_{available} > t_{processing} + t_{reaction} + t_{brake}$ => $t_{margin} > 0$

Then:

$$t_{available} = t_{processing} + t_{warn};$$

$$t_{warn} = t_{reaction} + t_{brake\ min} + t_{margin};$$

$$t_{reaction} = t_{driver\ reaction} + t_{transmis\ reaction};$$

$$t_{brake\ min} = \frac{v_{car}}{a_{brake\ max}}$$

$$t_{margin} = t_{warn} - \frac{v_{car}}{a_{brake\ max}} - t_{driv\ react} - t_{transm\ react} =$$
$$= t_{available} - t_{processing} - \frac{v_{car}}{a_{brake\ max}} - t_{driv\ react} - t_{transm\ react}$$

During the margin time car can move with the speed V_{car} or have been stopped and

$$s_{margin} \leq t_{margin} \cdot v_{car}$$

2. If $t_{available} = t_{processing} + t_{reaction} + t_{brake}$ => $t_{margin} = 0$

Then driver will have warning signal and will have time to stop with maximum brake force and without time margin:

$$t_{warn} = t_{reaction} + t_{brake\ min} = t_{driv\ react} + t_{transm\ react} + t_{brake\ min}$$

3. If $t_{processing} + t_{reaction} < t_{available} < t_{processing} + t_{reaction} + t_{brake}$

In this case driver will have warning signal, he will start to brake, but will not have enough time to stop before the collision point ($v_{car\ end} \neq 0$). In this case equations will be other:

$$t_{available} = t_{processing} + t_{warn}$$

$$t_{warn} = t_{reaction} + t_{start\ brake} = t_{driver\ react} + t_{transm\ react} + t_{start\ brake};$$

And in this case driver should use some maneuver to avoid the collision (like turn to the side of the parking car)

4. If $t_{processing} \leq t_{available} \leq t_{processing} + t_{reaction}$ => $t_{margin} = 0,\ t_{brake\ min} = 0$

In this case driver will have warning signal, but he will not have enough time to reaction and will not start the brake. In this case equations will be other, without movement of deceleration:

$$t_{available} = t_{processing} + t_{warn} = {}^{S_{coll}}\!/_{V_{car}}$$

5. If $t_{available} < t_{processing}$ then driver will not have warning signal before the collision. In this case also (we suppose car acceleration a=0)

$$t_{available} = {}^{S_{coll}}\!/_{V_{car}}$$

8.2.3.2. Test case 2.2. IoT Pedestrian Collision Avoidance Architecture with INS/GPS and Smartphone

GPS is a common device for vehicle position beaconing in the collision avoidance systems. But it has a set of well-known disadvantages. 4 visible satellites are required to get the precise position, that's why GPS could lose the signal inside the tunnels, buildings, bridges, and even high buildings in a city could be an obstacle for the satellites. Even in urban outdoor conditions the GPS accuracy is 20m or more, depending on the number of available satellites. Along with other problems with accuracy and latency of GPS which is the main issue for car moving at the high speed. Therefore GPS beaconing cannot provide the reliable and timely positioning for delay sensitive collision avoidance apps. INS is a classic reliable navigation system. But it has a high price and errors. The most significant INS error is a drift, which is accumulated over time. Low-cost INS cannot provide the accurate position because of huge drift. GPS corrected from INS can significantly improve the accuracy, data freshness and reliability of vehicle position detection [91]. Therefore we propose a structure of pedestrian collision avoidance system with a data fusion from INS/GPS sensors. The pedestrian doesn`t move so quickly like a car and GPS errors will be less than for the car, and it can be enough enhanced A-GPS technology in Smartphone.

The structure of the collision avoidance system is shown in Fig. 61. We suppose the car have a navigation module. The vehicle navigation module consists of a common low-cost Micro Electro Mechanical System (MEMS) and GPS. The pedestrian position is defined by his Smartphone with A-GPS technology. The pedestrian position (x_{ped}, y_{ped}) and car position (x_{car}, y_{car}) are beaconing to the IoT cloud database.

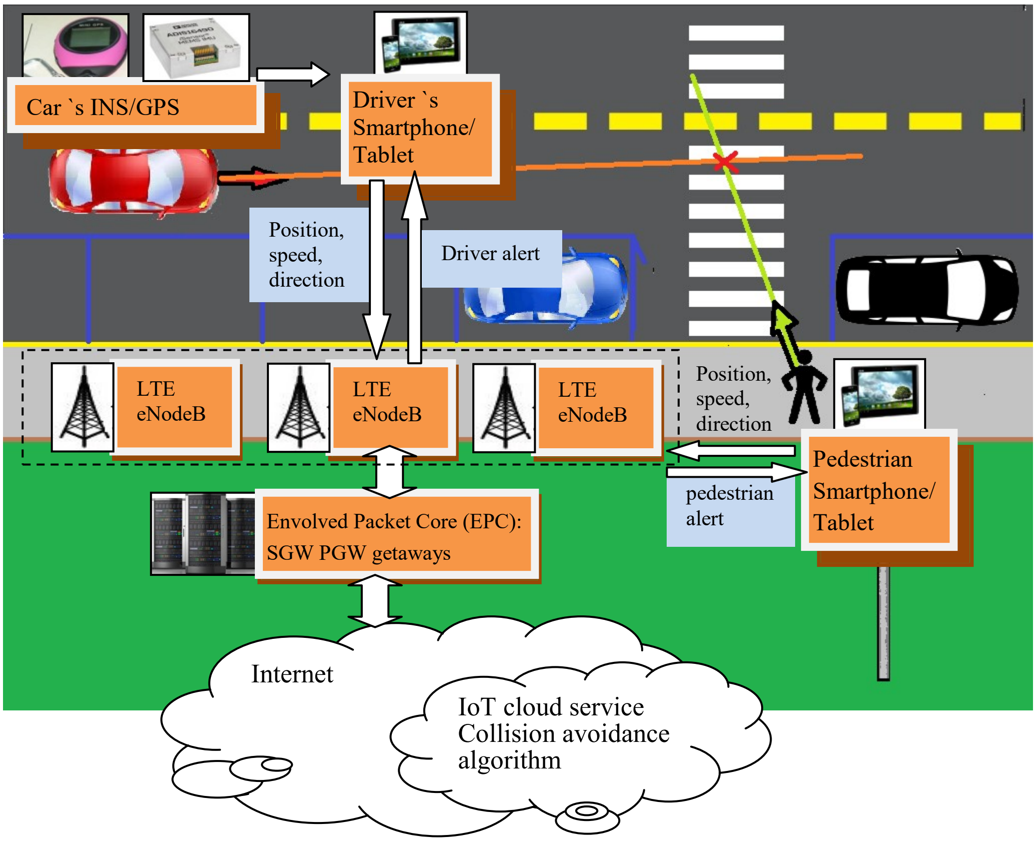


Fig. 61. Structure of the Pedestrian Collision avoidance system with INS/GPS over LTE and IoT

We suppose that the driver connects car sensors (INS and GPS) to the Smartphone/Tablet/laptop with internet over 4G/LTE-Advanced. Application for IoT positioning service (client part) has installed on this gadget. Server part of the IoT positioning service is running on the side of the IoT Cloud Provider (ICP). The IoT service provides car position acquisition to the cloud IoT data center using broadcast IoT protocol. Same for the pedestrian Smartphone, it has an app for pedestrian IoT service. But periodic beaconing can discharge phone in 5 hours [28]. The situation adaptive beaconing approach, which is presented in [28] can decide this issue. We suppose the beaconing frequency is situation adaptive and it depends on the car/pedestrian speed and mode (normally, in active mode, every 1 second).

The beacons sending to the IoT cloud contain geolocation, speed and direction of the movement. Then collision risk is evaluated by collision prediction algorithm in the IoT service for any pair of car-pedestrian in the safety zone. In the case of high collision risk warning message is sent to the driver/pedestrian Smartphone/Tablet.

8.2.3.2.1. INS/GPS data fusion

Inertial navigation systems (INS) are used to solve the problems of navigation in aircraft, naval ships, submarines, and spacecraft. INS is widely used due to their versatility and autonomy. Inertial system compared to the radio/satellite navigation systems has the following advantages [102]:

- autonomy
- continuity of positioning of a moving object;
- immunity;
- wide range of application;
- a weak dependence of the accuracy of the navigation information from the maneuvering of a moving object;
- the maximum amount of navigation information (position, speed, acceleration, vertical);
- high accuracy angle measurements of heading, roll and pitch, as well as vertically;

The disadvantage of INS is that the inevitable result of instrumental and technological errors over time accumulates the error in determining the location of a mobile object. It is therefore advisable to adjust the testimony of INS using other sources of information that do not have the main disadvantage of INS is the accumulation of error over time. The correction can be both periodic and continuous.

Another significant disadvantage of INS is its high price. Although there are many models of low-cost INS, but cheaper models have a significantly large errors compared to expensive.

According to the SiDAS project objectives driver assistance has to have low cost for the driver and low cost driver sensors. Therefore, cheap INS with the correction of errors from other systems has selected. Here is considered a method of increasing the accuracy of the INS based on the use of positional and velocity information from the GPS receiver. It is a classic method which is actual today [103], [91], and in Internet of Vehicle as well [104].

GPS measurements can be affected by errors:

- determine the coordinates of the satellites,
- errors caused by passage of signals from the satellite to the receiver,
- delay the signals in the atmosphere,
- electronic noise of the receiver.
- Errors of selective access.

The most significant error in the measurement errors are selective access (SA). These errors are largest reach tens of meters. The nature of changes in SA error is a low-frequency oscillations with a period of 8-10 minutes [103], which makes them smooth. Method of measuring pseudo-resistance using the GPS receiver provides higher accuracy, compared to traditional GPS receiver, due to the lack of error-selective access.

Error of the elements of the INS is evaluated traditional methods (statistical) or unconventional (scalar wave) processing of information received from the INS and GPS [105]. The difference between the navigation parameters defined INS and GPS is the difference of the errors of INS and GPS. Errors of the INS have a low frequency and changing with a period of 84.4 minutes, and GPS errors of high frequency random noise [103]. Differences in the spectra of errors allow us to estimate the error of the Ann, while the noise of the GPS is subject to aliasing.

There are two basic approaches to the problem of integration of INS and GPS [106], [107], [108]:

- centralized (closed) method;
- cascade (open) method.

When implementing a centralized method to the input of the estimation algorithm are received from the GPS information on the distance between the receiver and the satellites, and the speed of its change. In addition, the INS also receives information about the current navigation parameters.

The estimation algorithm (Kalman filter) implements the joint model errors of INS and GPS to determine the current navigation parameters. The main advantage of the centralized approach is the possibility of expanding the bandwidth of the GPS receiver without a substantial increase in noise measurements. In addition, the correction can be carried out by measuring only one satellite.

When the correction scheme of cascade type as measuring the parameters obtained from GPS coordinates and speed of the object. When using complexional system when using the cascade method, unlike the first method integration in this approach it is necessary to implement the decision of the navigation tasks directly in the GPS receiver that requires a review at least 4 satellites.

However, this approach has the following advantages:
- easy implementation, which is due to the fact that the dimension of the state vector is determined solely by the number of observed errors of ins;
- high reliability, because the correction of the ins is only for "well observed" errors of the ins. the versatility of the method for different inertial systems and operating conditions.

When comparing these two approaches, it should be noted that in the case of the use of data fusion in the city, where might be tunnels, tall buildings, the loss of several satellites is greater. That is, the number of satellites may be less than four. In this case, the first type of integration has the advantage, because he can make adjustments in the case of measurements coming from only one satellite. However, the time of failure of satellites for such objects is only a few seconds, during which it is possible to predict the behavior of the error of the Ann. Using cascading scheme allows you to create a simple and reliable estimation algorithm easy to implement. Thus, the most expedient is the use of cascade schema integration.

Methods of information processing in the INS/GPS integrated systems can be divided into two categories [103], [108]:

- Traditional methods Kalman filter (statistical methods).
- Non-traditional methods.

The most popular method of estimating the state vector is the Kalman filter. In the formulation of the optimal filter requires that the input and measurement noise was white. In the case of colored noise are shaping filters, the input of which is received white noise. To implement the Kalman filter requires a priori information about the correlation matrices of the input and measurement noise (Q and R). However, in real applications this information is usually set inaccurately. This may lead to divergence of the filtering algorithm. The implementation of the computational scheme based on the algorithm of Kalman is difficult for large values of the dimension of the state vector. To prevent these difficulties, developed a series of modifications of the Kalman filter. So, to reduce the amount of computation is proposed to use reduced Kalman filter. The basic idea is that the estimation of the Kalman filter is determined not to full, and for a truncated state vector. This UN-assessed components related to the input noise.

There are several versions of the Kalman filter, allowing the assessment of the state vector in the absence of accurate a priori information about the statistics of the input and measurement noise (Q and R). Such algorithms are called adaptive Kalman filters [103]. To build adaptive filters you can use the properties of the updated sequence. In [109] were considered algorithms for adaptive filters 1, 2 and k-th modifications, as well as the algorithm Yazvinsky. The proposed algorithms are efficient for large uncertainties in the a priori information. Using adaptive Kalman filter based on the analysis of the covariance matrix of the updated sequence is suitable for a case of unpredictable surges of measuring noise GPS in case of a sharp change "constellation" of observed satellites. Define a limit on the accuracy of estimation in the case of using the Kalman filter. The accuracy of the estimation is limited by the input noise level in the description of the model system. Thus, the main direction to increase the accuracy of estimation using the Kalman filter depends on the model view of the system in a more deterministic manner. However, such a representation is possible with an absolute knowledge flowing in the system, which is in practice rare and depends on the time scale of the model description.

An alternative approach to improving the accuracy of the description of the model is the wave estimation method, the principle of which is based on piecewise-determined representation of the input perturbations [108], [103].

8.2.3.2.2. VRU collision prediction algorithm

In this section is proposed the novel collision prediction algorithm which based on analysis of zones around the car, speed of approaching, time to collision and danger index.

There are set of vehicle collision avoidance algorithms. For example, in the paper [110] is presented the in-vehicle system for the pedestrian detection and situation classification according to danger estimation levels.

In the paper [28] is proposed three collision risk levels for pedestrian: risk-free, low-risk and high-risk. The situation is consider like a high-risk if the distance between the car and the pedestrian is less than some a priori calculated distance ω_{max} 200m for V2P communications .like a distance for communication, reaction and braking with a margin 2 sec. But there is not show the process of physical analysis and the probable collision point does not take into account.

In the papers [110] and [29] is shown an approach in which is calculated the probable collision point. In [110] is proposed the danger estimation and danger index calculation for in-vehicle ADAS based on zones for the car: safe zone, danger zone and imminent collision zone. In [29] and is proposed the evaluation of the danger situation based on difference time to collision for car and pedestrian and also the danger index. Therefore, the paper [29] is improved the calculation of the danger index. But in the [29] is not shown the calculation of time to collision. Also, in [110] and [29] absent the analysis of approaching of the car and pedestrian, direction of the movement is not take into account, collision point calculation can refer not to the future moment, but like“to the past moment”.

We propose to use different kind of notification for the driver according to the danger degree of the situation. That allows the driver to choose the appropriate braking strategy to avoid the collision. Unfortunately, it is not possible to avoid all dangers situation by the driver warning systems. For example, if pedestrian happens to get on the road one meter before the car on the high speed. Even in that case we can use high level emergency signal which allows the driver mitigate the pedestrian damage.

Our proposed algorithm has set of enhancements: 1) we propose our novel danger estimation with danger zones around the car to range the danger of situation both for visible and invisible pedestrian. Also driver warning algorithm will depends on the zone; 2) the calculation of the collision point is improved to avoid false notification. We propose take to the account the direction of the movement and speed of the approaching; 3) the danger index evaluation is changed.

We propose to include analyze of the relative speed of approaching in the algorithm for calculating the probable collision point and danger level. That allows us: firstly to reduce the false driver warning in the case of car and pedestrian move apart; secondly, to enhance the calculation of the danger index if objects approaching very fast.

The proposed algorithm:

1) pedestrian`s and car`s position and speed acquisition (x_{ped}, y_{ped}, v_{ped}), (x_{car}, y_{car}, v_{car});
2) danger zone evaluation;
3) calculation of the probable collision point (x_{coll}, y_{coll});
4) calculation of the speed of approaching;
5) calculation of the time to collision point for the car and pedestrian;
6) comparison of the difference in time to collision for car and pedestrian t_{coll} with the a priori defined threshold.

8.2.3.2.3. Estimation of danger zones and collision avoidance strategy

In the paper [110] is proposed the safe zones for the in-vehicle system for pedestrian detection. There are three zones: 1) safe zone in which time to collision is enough to stop the vehicle avoiding the collision (> braking distance); 2) danger zone, in which driver can perform a maneuver to avoid the collision (< braking, >response distance); 3) imminent collision zone is the closest zone where pedestrian collision is imminent. But this algorithm notify driver only about the necessity of emergency braking by danger signal, driver have no time to make decision and that can be stressful for the driver. Also is used only in-vehicle sensors and so, this algorithm is mostly for visible obstacle from the car, driver mostly should see the pedestrian, if he keeps attention. For the case with a priori non visible obstacle (pedestrian) the algorithm it is not fit and should be updated.

In addition we propose to increase driver situation awareness by informing the driver in advance about all pedestrians in the protected area of 20 sec., especially about non visible pedestrians. We propose to visualize (without emergency signal) all invisible pedestrians in 10 sec. like a red point on the map; even they have no collision point with the car, because pedestrians can change trajectory. Especially important, that we propose to warn driver with an acoustic signal/message about all pedestrians in the protected zone (there available time not more than 5 sec), even they have no collision point with the car. Therefore, we propose to evaluate situation like potential danger in this case. The zones of available time in 5 and 10 seconds depend on vehicle speed. So, driver will knows in advance, for example, about walking pedestrian near the uncontrolled pedestrian crossing, and will have a time to make a decision, he can reduce the speed and will be preparing to warning notification.

We propose evaluate danger zone based on the distance between the objects D_0 and their speeds (Fig. 62). Key parameter is the minimum time to collision $t_{coll\ min}$ – it is the time to collision of the car and pedestrian, if they move on the straight line between the car and pedestrian with their current speed (the minimum time to collision is differ from the time to collision point for car and pedestrian!).

The distance D_0 between car and pedestrian like a straight line:

$$D_0 = \sqrt{(x_{ped} - x_{car})^2 + (y_{ped} - y_{car})^2}$$

Calculation of the available time $t_{coll\ min}$ based on speed of the car and the pedestrian: Lets define relative speed

$$\vec{V}_{rel} = \vec{V}_{car} - \vec{V}_{ped} = V_{car}^2 + V_{ped}^2 - 2 \cdot V_{car} \cdot V_{ped} \cdot \cos\gamma$$

γ - the angle between the vectors $\vec{V}_{car,}\ \vec{V}_{ped}$;

α - the angle at which pedestrian oriented to the car (“visible” from the car);

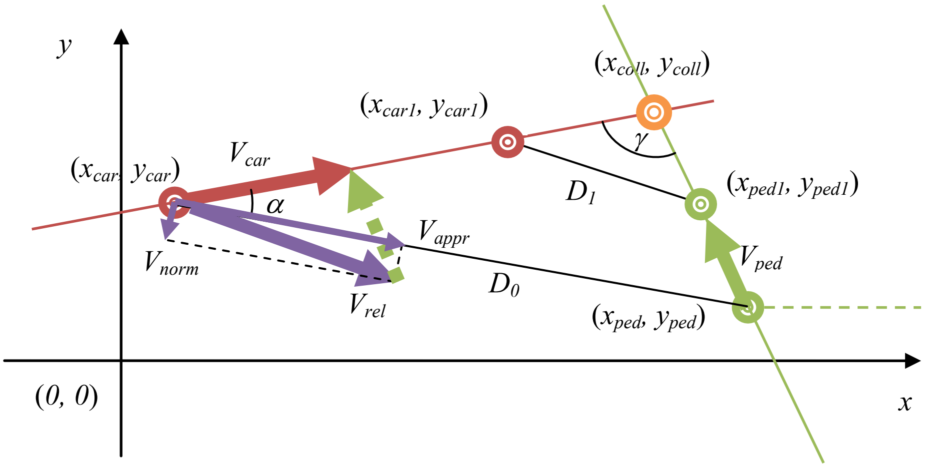


Fig. 62. Speed of approaching, change of the distance

In the moment t_1 distance between the objects will change. In the general case D_1 is not parallel to D_0 because of difference in speeds (Fig. 62):

$$D_1^2 = D_0^2 + (V_{rel} \cdot \Delta t)^2 - 2 \cdot D_0 \cdot V_{appr} \cdot \Delta t$$

We suppose $\frac{dD_1}{dt} = 0$ to find $t_{coll\,min}$

$$t_{coll\,min} = \frac{D_0 \cdot V_{appr}}{V_{rel}^2}$$

Also we suppose that the car and the pedestrian can change the direction and more worse case, than t_{coll} will be min, is if $V_{rel} = V_{appr}$. Than

$$t_{coll\,min} = \frac{D_0}{V_{appr}}$$

Proposed zones for the car:

1. Traffic advisory zone: 10 sec.< $t_{coll\,min}$ < 20 sec. The driver will get visualization of the invisible pedestrian like a yellow point on the map. If the trajectories of the pedestrian and the car have a collision point, the driver will NOT get warning signal.
2. Resolution advisory zone: $t_{processing} + t_{reaction} + t_{brake} + 5sec. < t_{coll\,min} \leq 10\ sec.$. The driver will get visualization of the invisible pedestrian like a red point on the map. Driver should be nicely, carefully and be prepared to the danger signal, he can reduce the speed. If the trajectories of the pedestrian and the car have a collision point, the driver will get warning signal.

3. Immediately brake zone: driver have to brake immediately, t margin <5 sec

   $$t_{processing} + t_{reaction} + t_{brake} \leq t_{coll\ min} < t_{processing} + t_{reaction} + t_{brake} + 5sec.$$

   Driver will get warning signal that the invisible pedestrian is in the protected area even they have no collision point (because the pedestrian near. If they have a collision point, driver will get emergency warning signal (acoustic and visual) and he should brake immediately.
4. Danger zone: driver have to brake immediately and use maneuver to avoid collision, t margin =0;

   $$t_{processing} + t_{reaction} < t_{coll\ min} < t_{processing} + t_{reaction} + t_{brake}$$

   Driver will get high level emergency warning signal (acoustic and visual) and collision avoidance maneuver recommendation (it is not the subject of this section).
5. Imminent collision zone: is the closest zone where pedestrian collision is imminent. t margin =0

   $$t_{coll\ min} \leq t_{processing} + t_{reaction}$$

   Driver will get high level emergency warning signal (acoustic and visual) and he should use emergency braking. System can give recommendations to mitigate the pedestrian damage (it is not the subject of this section).

8.2.3.2.4. Probable collision point and speed of approaching

First let consider the calculation of the probable collision point.

There are set of methods for calculation collision point. For example, in the paper [29] is shown an approach in which the probable collision point (x_{coll}, y_{coll}) is calculated based on coordinates and orientation angle of car and pedestrian (Fig. 63).

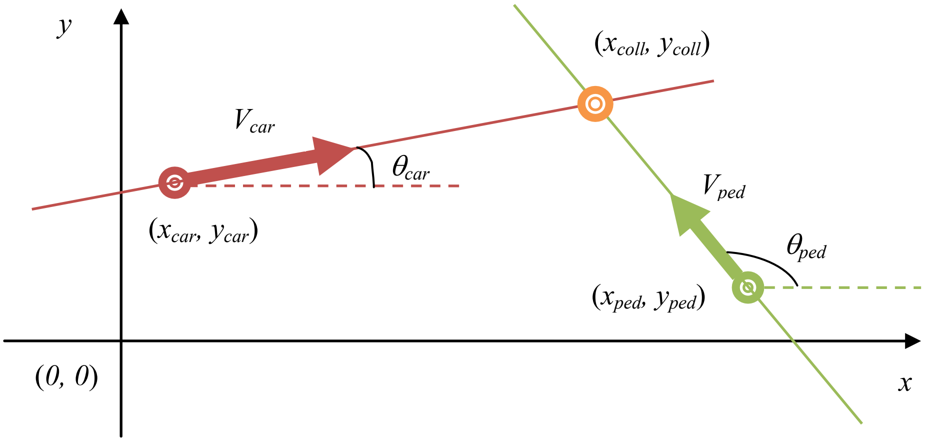


Fig. 63. Collision point calculation

Let consider the equations from [29]:

$$x_{coll} = \frac{(y_{car} - y_{ped}) - (x_{car} \cdot \tan\theta_{car} - x_{ped} \cdot \tan\theta_{ped})}{\tan\theta_{ped} - \tan\theta_{car}}$$

$$y_{coll} = \frac{(x_{car} - x_{ped}) - (y_{car} \cdot \cot\theta_{car} - y_{ped} \cdot \cot\theta_{ped})}{\cot\theta_{ped} - \cot\theta_{car}}$$

But these equations do not take into account direction of the movement, that car and pedestrian can go away from each other (Fig. 64), in this case according to the formula we will have collision point, but really intersection of the trajectories will refer to the moment “in the past”. Moreover, according to this formula, trajectories will not have intersection (collision point) only that they are ideally parallel line, which mostly impossible.

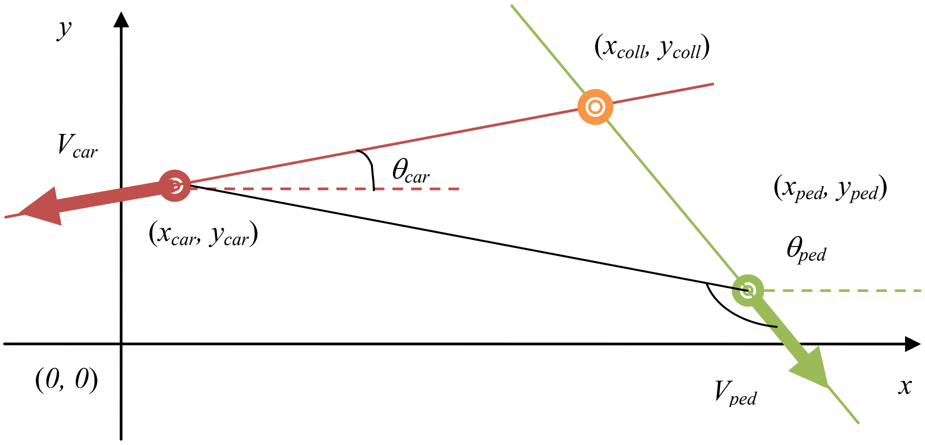


Fig. 64. The calculation of the collision point. The objects are moving apart.

We propose to enhance the calculation of the probable collision point.

At first, for more fast calculation we would exclude the calculation of the rotation angles with x axe for car and pedestrian. We propose calculation of the probable collision point based on current speed vectors of pedestrian and car and also prediction linear interpolation, will calculate by including previous and next position.

We would exclude false alarm of the driver by eliminating the calculation of collision point in the case than objects are move apart. In order to do that, we propose to include the analysis of the speed of approaching of the car and the pedestrian.

Let consider the relative speed of car and pedestrian:

Let suppose that the vehicle is travelling in a straight line (road is a line) with the constant speed $\vec{v}_{car} = const$ and without acceleration $\vec{a}_{car} = 0$, and the vehicle move towards to the probable collision point (x'_{coll}, y'_{coll}) in the GPS coordinates.

Let introduce the new road coordinate system based on the ground and connected with the road, there an axis x have the same direction with the road.

In the road system probable collision point is (x_{coll},0), projection of the vehicle speed on the road axis (V_{car},0).

The conditions for the rapprochement of the vehicle to the collision point are:

$$\begin{cases} V_{car} > 0, \;\; x_{coll} > x_{car} \\ V_{car} < 0, \;\; x_{car} > x_{coll} \end{cases};$$

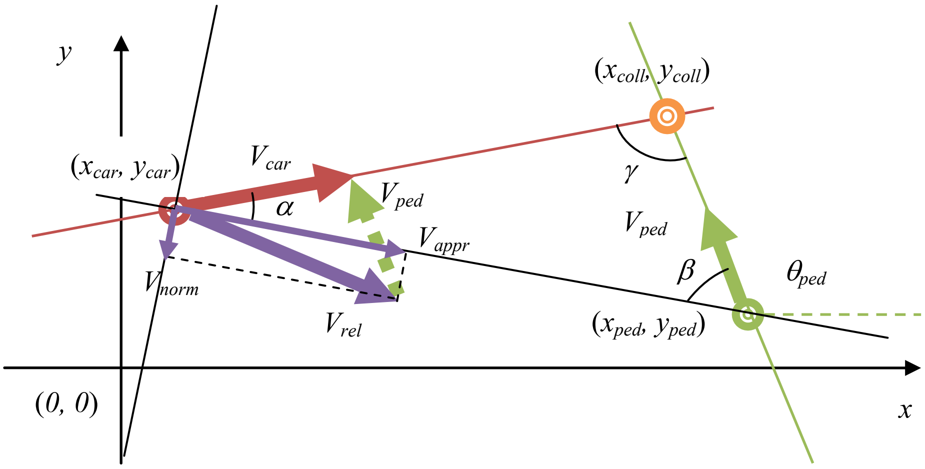


Fig. 65. The relative speed and the speed of approaching.

$$\vec{V}_{rel} = \vec{V}_{car} - \vec{V}_{ped} = V_{car}^2 + V_{ped}^2 - 2 \cdot V_{car} \cdot V_{ped} \cdot \cos\gamma$$

The speed of approaching is the projection on the axis x_{rel} (the line between the position of the car and pedestrian) in general case:

$$V_{appr} = V_{car} \cdot \cos\alpha + V_{ped} \cdot \cos\beta$$

α - the angle at which pedestrian oriented to the car (the angle at which the pedestrian “visible” from the car);

β - the angle at which car oriented to the pedestrian (the angle at which the car“visible” for the pedestrian);

If the $V_{appr} > 0$ the collision point will calculate.

If $V_{appr} < 0$ the objects are move apart and collision point will not calculate.

For the case in the Fig. 65:

$$V_{appr} = V_{car} \cdot \cos\alpha + V_{ped} \cdot \cos\,\beta = V_{car} \cdot \cos\alpha + V_{ped} \cdot \cos(180 - \alpha - \gamma)$$
$$= V_{car} \cdot \cos\alpha - V_{ped} \cdot \cos(\alpha + \gamma)$$

If objects are moving apart (for the case in the Fig. 64)

$$V_{appr} = V_{car} \cdot \cos\alpha + V_{ped} \cdot \cos\,\beta = V_{car} \cdot \cos\alpha + V_{ped} \cdot \cos(180 - (180 - (180 - \alpha) - \gamma))$$
$$= V_{car} \cdot \cos\alpha - V_{ped}$$
$$\cdot \cos(180 - \alpha + \gamma) = V_{car} \cdot \cos\alpha - V_{ped} \cdot \cos(180 - \alpha + \gamma)$$

8.2.3.2.5. Pedestrian kinematic model and linear position prediction

Let define a kinematic model for a pedestrian. We suppose that the pedestrian moves in two-dimensional Cartesian space $R^2{}_2$. Let present the pedestrian like a mass point with the coordinates $(x_p, y_p) \in R^2{}_2$. We suppose pedestrian`s trajectory is a curvilinear irregular deterministic motion which describes by time-dependent curvilinear irregular function. Let present that function in the Euclidean vector space with radius-vector $r_p(t)$:

$$\overline{r_p} = \overline{r_p}(t)\;\; or\;\; \begin{cases} x = x_p(t); \\ y = y_p(t); \end{cases}$$

Pedestrian moves with the speed v_p and the acceleration a_p. Projection on the two-dimensional ground coordinate system (GPS)

$$d\vec{r} = r_x dx + r_y dy$$

$$\vec{V_p} = \frac{d\vec{r}}{dt} = \frac{dr_x}{dt}dx + \frac{dr_y}{dt}dy$$

$$\vec{a}_p = \lim_{\Delta t \to 0} \frac{\Delta\vec{V}}{\Delta t}$$

Lets describe the pedestrian kinematic model like a function

$f(t, x_p, y_{p,}, v_{px}, v_{py}, a_{px,} a_{py})$.

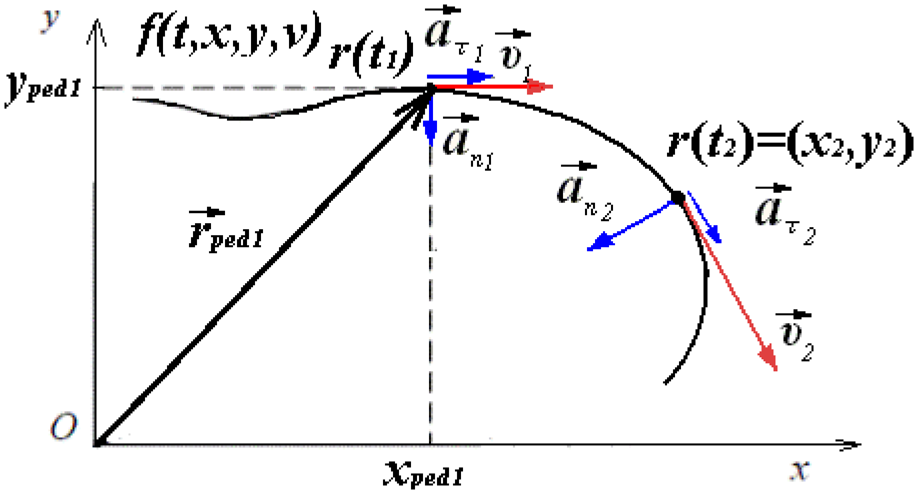


Fig. 66. Pedestrian trajectory

The equations of the pedestrian motion are explicitly non-linear.

In the case, if angle acceleration ε=const (**Fig. 66**);

$$\vec{a} = \overrightarrow{a_\tau} + \overrightarrow{a_n} = \vec{n}\frac{V^2}{\rho} + \vec{\tau}\cdot\frac{d^2 s}{dt^2} = \vec{n}\frac{V^2}{\rho} + \vec{\tau}\cdot\frac{dV}{dt}$$

$$\varphi = \varphi_0 + \overrightarrow{\omega_0}\cdot dt + \frac{\varepsilon\cdot dt^2}{2}$$

To simplify the equations, let present them with discrete numerical determinated modeling for computing. Let set the time step $h=t_n-t_{n-1}$. Than pedestrian trajectory is

$$\bar{r}_p = \bar{r}_p(t) \;\; or \;\; \begin{cases} x_p = \{x_1 = x_p(t_1), x_2, x_3, \dots x_n\}; \\ y_p = \{y_1 = y_p(t_1), y_2, y_3, \dots, x_n\}; \end{cases}$$

Let suppose that we know pedestrian position $\vec{r}_{p\,i}$ or $(x_{p\,i}, y_{p\,i})$ and velocity $\vec{V}_{p\,i} = \dot{x}_{p\,i}$ at the current moment t_i. Other time derivative (acceleration, etc) of the pedestrian in the moment t_i will define from the equations

$$\vec{v}_{p\,i} = {}^{d\vec{r}_{p\,i}}\!/_{dt}; \;\; \vec{a}_{p\,i} = {}^{d^2\vec{r}_{p\,i}}\!\Big/_{dt^2} = {}^{d\vec{v}_{p\,i}}\!/_{dt};$$

Let use current values to predict the position and speed of the pedestrian in the future moment $t_{i+1}=t_i+h$.

Let make also motion extrapolation like linear motion on the time set between current moment $t_1=t_{cur}$ and future moment $t_2=t_{fut}$ (**Fig. 67**)

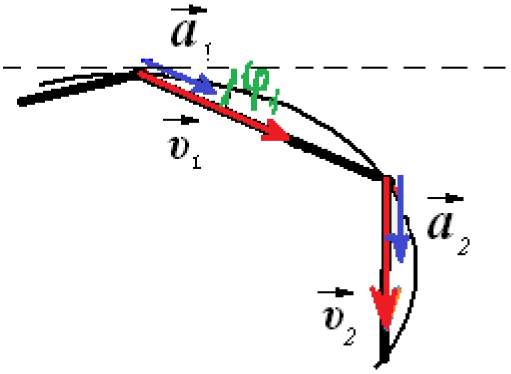


Fig. 67. Trajectory extrapolation

So, on the equations became linear irregular motion without normal component of the acceleration a_n. In the current moment t_{cur} pedestrian has position with the coordinates (x_{cur}, y_{cur}), in the moment t_{fut} he has position with the coordinates (x_{fut}, y_{fut}). Then future pedestrian position is defined with recurrence formula:

$$(x_{p\,fut}, y_{p\,fut}) = \begin{cases} x_{p\,cur}, \quad v_{x\,p\,cur}=0, \quad a_{x\,p\,cur}=0; \\ x_{p\,cur} + v_{x\,p\,cur}\, h\cos\varphi_p, \quad v_{x\,p\,cur}\neq 0, \quad a_{x\,p\,cur}=0\,; \\ x_{p\,cur} \pm v_{x\,p\,cur} h\cos\varphi_{p\,cur} \pm \dfrac{a_{x\,p\,cur} h^2\cos\varphi_{p\,cur}}{2}, \quad v_{x\,p\,cur}\neq 0, \quad a_{x\,p\,cur}\neq 0; \\ y_{p\,cur}, \quad v_{y\,p\,cur}=0, \quad a_{y\,p\,cur}=0; \\ y_{p\,cur} + v_{y\,p\,cur} h\sin\varphi_{p\,cur}, \quad v_{p\,cur}\neq 0, \quad a_{pcur}=0\,; \\ y_{p\,cur} \pm v_{y\,p\,cur} h\cos\varphi_{p\,cur} \pm \dfrac{a_{y\,p\,cur} h^2\cos\varphi_{p\,cur}}{2}, \quad v_{y\,p\,cur}\neq 0, \quad a_{y\,pcur}\neq 0; \end{cases}$$

8.2.3.2.6. Time to collision point for the car and the pedestrian

Time to collision is the most important criterion for the collision avoidance.

As was mention before, minimum time to collision we can evaluate according to the formula:

$$t_{coll\,min} = \frac{D_0 \cdot V_{appr}}{V_{rel}^2}$$

We have take $t_{coll\,min}$ into account during the evaluation of the danger zone.

But that is a worse case, and we still cannot be sure that objects will arrive in the collision point in the same time. That's why, we would calculate exactly times $t_{coll\,ped}$ and $t_{coll\,car}$ than the car and the pedestrian will arrive in probable collision point for more precise estimation if collision can really happened.

As was mention before, ***the proposed estimation of the time to collision for the car*** in the case than driver not aware about the collision like a motion without acceleration:

$$t_{coll\,car} = {S_{coll\,car}}/{V_{car}} = \frac{\sqrt{(x_{coll} - x_{car})^2 + (y_{coll} - y_{car})^2}}{V_{car}}$$

We propose estimation of the time to collision for the pedestrian like a motion without acceleration:

$$t_{coll\,ped} = {S_{coll\,ped}}/{V_{ped}} = \frac{\sqrt{(x_{coll} - x_{ped})^2 + (y_{coll} - y_{ped})^2}}{V_{ped}}$$

We have improved an approach in [29] and [110], there the probable collision situation is evaluated based on a comparison of the difference between time to collision for the car and the pedestrian with some a priory determinate threshold:

$$t_{coll\,car} - t_{coll\,ped} < \delta$$

In the paper in [29] and [110], the threshold δ is calculated based on the driver reaction time $t_{driver\,reaction}$ and braking time of the vehicle t_{brake}:

$$\delta = t_{driver\,react} + t_{brake}$$

We have improved calculation of the time threshold δ with the car`s transmission reaction $t_{transm\ react}$ and the processing time $t_{processing}$, which includes time for V2X and IoT communication:

$$\delta = t_{processing} + t_{driver\,react} + t_{transmis\,react} + t_{brake}$$

8.2.3.2.7. Collision avoidance algorithm:

For any pair of objects (vehicle and pedestrian) every 1 second (or more on a high speed) is calculated a distance, speed of the approaching and probable collision point. After that, the probable times to collision for car and pedestrian are evaluated. Then, the zone is calculated, based on difference in times to collision and distance between the car and pedestrian, the potentially danger situations are extracted and driver will warn about the pedestrian. If situation is potential unsafe, the danger index is evaluated. If danger index is high driver will receive the high warning acoustical signal with recommendation about collision avoidance.

8.2.3.3. Test case 2.3. IoT Pedestrian Collision Avoidance Architecture with car camera and pedestrian Smartphone

The same architecture, but take into account the video from in-vehicle camera Fig. 68. I suggest the same IT structure that was proposed the test case 1.2: IoT Cloud Platform with NoSQL DB Hana and data store Hadoop for non-structured video data. The difference only, that the detection algorithms for the Hadoop should be for pedestrian detection, and not for car detection. Also the pedestrian don`t move so quickly like a car and GPS errors will be less.

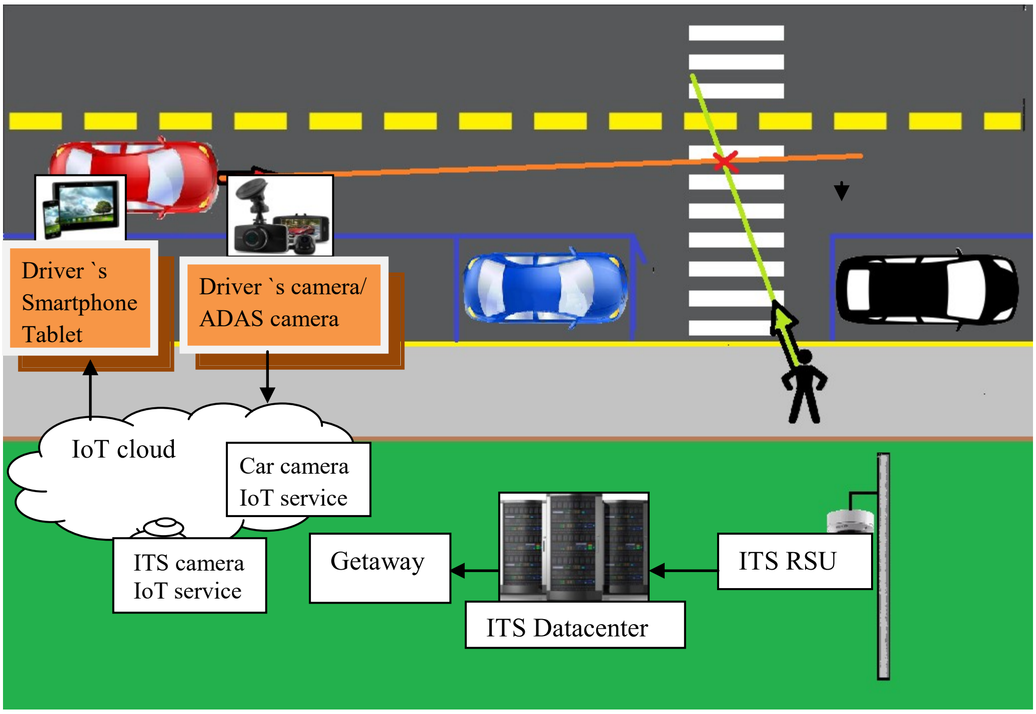


Fig. 68. An architecture of SiDAS pedestrian collision avoidance

Time margin analysis for the system is provided in the previous sections.

8.3. Conclusions for the Test cases

The most urgent issues for real-time drive assistance process are execution time and miss-rate of the intelligent processing algorithms like pedestrian detection from video, collision avoidance, predictive algorithms, etc. These intelligent algorithms and real-time computing define the high level requirements to the processing and memory resources.

IoT allows us move the logic (business intelligence) and DB to the extremely powerful Cloud server side. It can significantly improve performance of the existing ADAS intelligent algorithms, as well as allows to use more sophisticated and lower miss rates logic, as well as more professional and heavy DBMS (move from MySQL to Postgre, Oracle, DB2, SAP or NoSQL DB).

But the IoT delay and seamless wide communication channel are main issues for performance of server side IoT intelligence applications. IoT may be deficient in latency caused by geographical distance between sensors and IoT platforms hosted in remote Cloud/Fog Datacenters [92]. This is particularly relevant for delay-sensitive vehicle ADAS applications. We have shown that the IoT latency can be huger, but it is comparable with latency caused by DSRC communication in VANET and ITS networks and can be appropriate according to the ETSI standard. And we can run safety apps in the Cloud, it can be more effective with using early driver notification about VRU and other vehicles and with predictive algorithms.

In the future, the problem of IoT latency caused by geographical distance can be solved by using cellular operators Datacenters infrastructure like in solution Mobile Edge Computing (MEC). MEC is one of technologies for the future 5G communication standard. It is exploiting cellular system`s processing time and storage space for delay-sensitive local calculation needed by the surrounding sensors [92].

Thesis conclusions and future work

This research provides a survey of ITS, VANET and other vehicle network systems. It contains deep analysis and comparison of the different implemented solutions of the last few years. It filters the technical details from different research and projects. Current work contributes a technological analysis of the wide range of the vehicle communication projects in industry and academia, seeks up-to-date technologies, optimal decisions and directions of the development for the future. The research contains an analysis of the advantages and disadvantages of the different systems.

This research proposed the driver assistance system based on Vehicle-to-X (V2X) communications and integrated the challenges of IoT paradigm. We have presented a general design approach for a new SiDAS architecture which improves existing systems in the aspects of integrity, compatibility and possibility to process data from the common driver`s devices (Navigator, Smartphone, Tablet …), as well as infrastructure data from ITSs, Vanets. We have developed the a IoT reference model for road safety applications using common devices. The proposed SiDAS approach with fusion acquisition results from multiple sensors and gadgets providing enhanced safety for road users: cars and VRU (pedestrians).

In the research we have shown the way to improve high-rate traffic danger awareness by Vehicle-to-X and Pedestrian-to-X communications using IoT. First of all, the developed system based on IoT allows to fuse a car`s sensors data with the infrastructure sensor data. And second of all, the IoT interconnects them with powerful IoT Cloud Datacentres.

Future work:

We would like to develop data fusion algorithms for Safe Intelligent DAS using position and video data from driver`s gadgets and infrastructure, and also emergency notification using common gadgets.

We would like to develop data fusion algorithms using critical data from ITS or Vanet;

We would like to build the prototype of the integrated system using V2X and IoT communication, ITS information;

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