Internet of Vehicles and Connected Smart Vehicles Communication System Towards Autonomous Driving

Amal Hbaieb (amal.hbaieb@utt.fr)
Universite de Technologie de Troyes
Samiha AYED
Université de Technologie de Troyes: Universite de Technologie de Troyes
Lamia CHAARI
Centre de Recherche en Numerique de Sfax

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Amal Hbaieb · Samiha Ayed · Lamia Chaari

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Abstract Internet of Vehicles (IoV) is one of the attractive solutions that revolutionized automotive services. IoV is the key concept toward smart and autonomous cars. Providing different wireless connectivity's for vehicles permits the communication inside and outside the vehicle. These connectivities allow the vehicle to interact with other vehicles and with its environment. Autonomous driving is an innovative automotive service that will be enabled by the technology advancement related to IoV and connected cars. Big data technology has a significant impact on the development of autonomous driving and IOV concept as it refers to a huge interactive networks of information. In this paper, we focus on wireless technologies and the communication system to provide Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I) or Vehicle-to-Road (V2R), Vehicle-to-Sensor (V2S), Vehicle-to-Human (V2H), Vehicle-to-Cellular (V2C), Vehicle-to-Grid (V2G), and Vehicle-to-Internet (V2I) connectivities. Accordingly, this paper proposes a novel planning scheme for internet connected and autonomous driving vehicles. Particularly, we present the principal components and how they should be distributed across this kind of architecture; i.e., identifying information flows, required exchanged data and basic functionalities required to build autonomous driving service as well as the holistic hardware and software architecture involving the in-car gateway.

Amal Hbaieb
University of Technology of Troyes, LIST3N laborator, Troyes, France
E-mail: amal.hbaieb@utt.fr

Samiha Ayed
University of Technology of Troyes, LIST3N laborator, Troyes, France
E-mail: samiha.ayed@utt.fr

Lamia Chaari
CRNS-SM@RTS (Laboratory of Signals, systeMs, aRtificial Intelligence and neTworkS), Sfax, Tunisia
E-mail: lamiachaari1@gmail.com

Keywords Vehicular network · IoV · VANET · Gateway · Connected smart vehicles · Autonomous driving

1 Introduction

Internet of Vehicles (IoV) is a complex integrated network system [1][2], which connects people within automotive, different automotive with different environment entries in cities [3]. IoV like phones, in which vehicles can run within the whole network, and obtain various services by swarm intelligent computing [4][5] with people, vehicles, and environments. Connected cars permit people to stay connected more frequently and consumers interest in the connected cars is growing. Automotive stakeholders identified new and significant business opportunity for connected cars and IoV. It is expected that the numbers of intelligent connected cars will exceed 381 million (from 2020). The next wave of innovation in transportation will be reached through a new generation of cars connected to internet and that interact with others cars and with transportation infrastructure. Furthermore, this new generation of cars will be self-driving cars equipped with autopilot allowing them to drive themselves in different road situations as well as in traffic jams. Besides that, researches [6][7] are going ahead to highway autopilot with lane changing based on blind spot technology to shift lanes. The following step is toward driverless vehicles that do not require the presence of a driver behind the wheel. Accordingly, automakers and car companies are ramping up their connected cars. Indeed, IoV allows automotive companies to obtain data from vehicles that could be analyzed to get valuable information and knowledge on how drivers use their vehicles to enhance the performances of their vehicles and to advance the development of driverless vehicles. Big data has an significant impact on the development of autonomous driving and IOV concept as it refers to a huge interactive networks of information. Big data technologies have come to deal with the massive generated data in real time within such vehicular frameworks. Nowadays, many car manufacturers and software developers have involved in the challenge of providing innovative solutions for driverless vehicles. Accordingly, many projects are ongoing. Among the European project focused on Intelligent Transportation Systems (ITS), we cite AutoNet2030 [8] which connects cooperative systems for intelligent transportation and automated driving research domains. AutoNet2030 addressed the cooperation issues between vehicles with different capabilities to increase the fluidity and the safety of the traffic systems. The cooperative automated driving paradigm is based on a decentralized decision-making approach powered by mutual information sharing among neighbor's vehicles and by sensor-based lane-keeping. EU LSP AUTOPILOT is another European project [9] with the objective to develop Internet of Things; IoT-architectures and platforms which will bring Automated Driving [10][11] towards a new dimension. The autopilot consortium is working on new advanced architecture [9] involving three zones: car zone, cooperation zone, and smart city zone. In this context, our contribution in this paper is to identify and to specify the required communication system for IoV and connected cars for the three zones. This paper is organized into five sections as follows: Section II is dedicated to related works and recent researches focused on IoV, Connected Smart Cars (CSC) and autonomous and driverless mechanisms. Section III provides automotive system evolution from Vehicular AdHoc Networks (VANET) towards IoV and CSC. In Section IV, we conduct our main discussion focused on the IoV communication system where we identify the three zones forming the envisaged vehicular network. Section V discusses and identifies the in-car gateway providing vehicle connectivity. Section VI highlights information flows and required exchanged data and basic functionalities for autonomous driving service delivery, furthermore, this section supports our proposal through a use case considering autonomous lanes changing with a focus on the communication and on exchanged messages between the diverse involved entities. Finally, section VII concludes the paper. Table 1 lists acronyms used throughout this paper.

2 Related works

Recently, many research activities and projects were carried related to automotive communication systems. Accordingly, in this section, we present the most recent research papers related to three keywords in correlation with our contribution, which are IoV, CSC and autonomous driving.

2.1 IoV related works

This section refers some recent existing contributions that are written in the context of IoV networks. Indeed, we organize these works according to their applied technologies. We outline the conceived approaches that include current advanced technologies such as Information Centric Network (ICN), Software Defined Networking (SDN) and Blockchain. Furthermore, we expose briefly the application of big data technology in vehicular network environments.

2.1.1 IoV based ICN

In view of the fast development of IoV and the IP network problems (security and quality of services for real-time traffic), recent contributions as for example in [[12]-[20]] propose the deployment of IoV solutions over the new generation of the Internet Protocol (IP) network called ICN. In [12], the authors proposed new architecture named CCN-IoV that deploys content chunks of Content-Centric Network (CCN) in the network layer. The authors evaluated the performance of CCN-IoV using Named data networking (NDN) simulator. Their primary results confirm the advantage of CCN in the automotive context. In [13] authors designed CRoWN, a content-centric framework for VANET networks. CRoWN provides content-centric Layer-3

Table 1 *List of Acronyms*

Acronym	**Full-form**
IoV	Internet of Vehicles
V2V	Vehicle-to-Vehicle
V2I	Vehicle-to-Infrastructure
V2R	Vehicle-to-Road
V2S	Vehicle-to-Sensor
V2H	Vehicle-to-Human
V2C	Vehicle-to-Cellular
V2G	Vehicle-to-Grid
V2I	Vehicle-to-Internet
ITS	Intelligent Transportation Systems
IoT	Internet of Things
CSC	Connected Smart Cars
VANET	Vehicular Ad-Hoc Network
IP	Internet Protocol
CCN	Content-Centric Network
NDN	Named data networking
RSU	Road Side Unit
SDN	Software-Defined Networking
AI	Artificial Intelligence
NLP	Natural Language Processing
ADAS	Advanced Driver Assistance Systems
HD	High Definition
CDCP	Cooperative Driving Control Protocol
DSRC	Dedicated Short Range Communication
WAVE	Wireless Access in Vehicular Environment
MAC	Medium Access Control
PHY	Physical layer
SAE	Society of Automotive Engineers
MANET	Dedicated Short Range Communication
QoS	Quality of Service
PDR	Packet Delivery Ratio
RTT	Round Trip Time
FC	Floating Content
HRM	Home Repository
AFS	Auxiliary Forwarding Set
ACO	Ant Colony Optimization
PB	Pseudo Bayesian
FCR	Fast Conflict Resolution
GPS	Global Positioning System
RFID	Radio Frequency Identification
V2X	Vehicle-to-Everything
WIFI	Wireless Fidelity
ECU	Electronic Control Unit
CAN	Controller Area Network
MOST	Media Oriented Systems Transport
3GPP	Partnership Project
LTE	Long-Term Evolution
CPU	Central Processing Unit
RTOS	Real-Time Operating System
CAF	Content Adaption Framework
API	Application Programming Interface

and Layer-4 operations implemented over the IEEE 802.11p layers. Vehicles and roadside units act as providers, when they own and deliver content or as consumers when they request contents. Each content is assigned a unique persistent name. CRoWN performance evaluation against the legacy IP-based approach was done using NS2 simulator, their obtained results demonstrate that the CRoWN outperforms the legacy IP-based approach. These preparing the way for the content-centric vehicular networking. In the same context, authors in [14] extended the CCN framework to CCVN in order to support content delivery on top of IEEE 802.11p vehicular technology. In [15] authors proposed a holistic NDN solution that codifies the demands of data traffic in NDN content names and shapes dynamically the NDN forwarding decisions to ensure the suitable prioritization. Simulation results showed that the proposed solution succeeds in achieving differentiated traffic treatment, while keeping traffic load under control. The work [16] introduced an ICN architecture which is vehicle location-oriented. The location data is employed to enhance the content search and request procedure, by directing interest packets near the area of a known vehicle with the content. The simulations that were conducted in this work demonstrated that the architecture succeeded in alleviating the broadcast storm problem, and hence improving the content delivery especially in terms of delay. Authors in [16] were interested in cost efficient multimedia content delivery in VANET by leveraging the ICN features. Their proposal focused mainly on content mobility and supply-demand balance, which greatly impact the cost-efficient performance. The work included adaptive heuristic mechanisms to achieve an optimal delivery by considering (i) priority-oriented path selection, (ii) least-required sources maintaining, and (iii) on-demand caching improvement. The proposal evaluation showed an improved performance. In [18], for example, authors proposed an NDN-based framework named GeoZone for forwarding interest packets in vehicular networks, and hence for reducing the network flooding. Their contribution consists of a geo-referenced content naming scheme to build a dissemination zone with node GPS coordinates, besides a zone forwarding mechanism for limiting the content requests flooding. This framework, however, still need a more detailed evaluation, considering other different factors such as vehicle speed impact. A service-oriented system architecture based on NDN for VANETs was also introduced in [19]. This architecture suggested a global naming scheme that contains services category (i.e., safety, transit information, and infotainment), a service sublayer for enabling requests management and information exchanging schemes, as well as a network load-based service prioritization policy. Simulation-based performance evaluation demonstrated that the solution is effective in managing services, yet, time sensitive services management should be further tackled. Another framework for vehicular NDN communications (named MobiVNDN) [20] was presented to support high mobility in related applications. The work refers to proposing a content advertisement scheme for content sources to report obtainable content objects, besides a messages redundancy handling technique and a mechanism for alleviating the negative impacts of source mobility. MobiVNDN proved its efficiency in terms of dealing with mobility effects and wireless communication medium unreliability. Besides, we refer that some ICN based IoV surveys addressed specific related theme, such [21] [22]. The paper [21] presented a functional-based taxonomy of ICN caching schemes within vehicular networks, to help in exploring the benefits of ICN as an ideal candidate framework for the deployments of VANETs. Moreover, the survey concluded by quantitative and qualitative analyses to enlist the major developments in caching schemes and elaborate the evolution of ICN caching schemes and their operational mandates with their applicability in vehicular networks. The research [22] surveyed the integration of ICN in vehicular networks, where further the authors conducted simulations to analyze the speed effect on VANET performance. Mainly throughput and packet delivery ratio parameters were considered.

2.1.2 IoV based SDN and Cloud

Currently, the vehicle is a sensing platform, gathering information from the vehicle, from its surrounding and from other vehicles and infrastructures and feeding it to drivers to assist in safe navigation, to manage intelligently the traffic and to control pollution. The IoV will be a distributed transport architecture able to make its own decisions about driving safety customers to their required destination. Accordingly, IoV will have communications, intelligence, storage, and learning capabilities. The Vehicular Cloud will promote the transition to the IoV providing required services by the autonomous vehicles. Authors in [23] discussed the evolution from Intelligent vehicle grid to autonomous, IoV and vehicular Cloud. They identified the main advantages of internet of Autonomous Vehicles and its related challenges for content distribution. Furthermore, they showed that a vehicular cloud model and an ICN architecture are potential design aspects toward autonomous vehicles. Even though cloud computing offers high storage, compute and networking services capabilities, the IoV still suffers from high processing latency and the lack of location awareness approaches. To address those problems authors in [24] proposed SDCFN architecture in the IoV that integrates SDN and fog computing. SDN affords flexible centralized network control. Meanwhile fog computing extends storing and computing to the edge of the network in order to reduce latency compared to the cloud and to enable location awareness. The SDCFN architecture is structured into four layers: (i) infrastructure layer made up of intelligent vehicles with on board units with processing units, communication units supporting 3G/4G /LTE/WiMax, sensors and localization systems, (ii) fog computing layer that consists of RSUs with computing and storage capabilities that support openflow protocol to communicate with the SDN controllers, (iii) SDN control layer; where SDN controllers send flow table to cloud/fog network and set data forwarding rule to control globally the cloud/fog network. Furthermore, to solve the load balancing problem and to enhance the Quality of Service (QoS) by decreasing the latency, the authors conceived a novel modified constrained optimization particle swarm optimization algorithm based on SDN, and (iiii) Cloud computing layer; is composed of high performance server clusters able to collect, store, and analyze vast amounts of data.

2.1.3 IoV based Blockchain

More recently, Blockchain technology is having an increasing interest as it may provide several services in vehicular networks by dint of its features especially the security aspect which is the top feature. In fact, Blockchain can be applied to deal with centralization, security, and privacy issues, when storing, tracking, managing, and exchanging data related to vehicles, as well as traffic conditions, traffic violations, surveillance, and weather information. As example, authors in [25] explored the integration of Blockchain with NDN-based VANET. They introduced a reputation-based Blockchain approach to enforce the security of the interest forwarding process, as well as the data forwarding plane and the content caching in NDN-based vehicular networks. The simulation results proved the effectiveness for this proposal to forward valid interest and cache trustworthy content. In [26], authors employed also a double layer Blockchain to build a data-sharing system in NDN vehicuar networks. In the bottom layer, vehicles nodes are grouped based on their interests, and each group maintains a private Blockchain where vehicles perform as miners to generate blocks. For the upper layer, Road Side Units (RSUs) nodes preserve a consortium Blockchain for data sharing among the vehicle groups, and data requests are submitted to nearby RSUs for further matching. Reference [26] validated the secure information exchange fostering by using the elaborated data sharing mechanism. The approach proposed in [27] aimed to allow efficient authentication and access control mechanisms in SDN vehicular networks. A set of interconnected Blockchain sub-networks was presented to improve the scalability aspect. An authentication and key agreement protocol that is Blockchain-based exhibited also its feasibility for the IoVs in [28]. The Blockchain was integrated in this protocol for multiple trusted authority to manage the ledger that contains vehicle related information. Moreover, AI has been proposed as an opportunity to handle Blockchain tasks with effective way in IoV context. In [29], an Artificial Intelligence;AI-based Blockchain scheme was established to foster the implementation of more secure smart contracts in IoV. The scheme showed that the AI and Blockchain combination succeed to make smart contracts intelligent contracts by using the Natural Language Processing (NLP) which gived auto coding feature for the smart contracts. Blockchain has been further employed in developing the trust-based vehicular networks models [[30]-[35]]. For instance, we refer the research [30] that applied Blockchain to elaborate an efficient trust management in IoV. In conjunction with smart contracts, the designed approach used physical unclonable functions, certificates, and dynamic proof-of-work to provide a secure IoV framework for storing trusted vehicles and preventing malicious ones.

2.1.4 Big data in IoV

IoV should support the dissemination, storage, and processing of the big data. In return, IoV profits from big data technology in terms of characterization, performances assessment and big data assisted protocols implementation. Different methods used by big data were presented to explore the characteristics of VANETs and improve their performance in [36]. Authors in [37] also discussed the integration of both IoV and big data concepts in vehicular networks environments. Particularly, they examined the applicability of big data for autonomous driving vehicles. Besides, they elaborated the emerging issues of IoV with big data. A vehicle traffic management method that uses big data was proposed in [38]. The work aimed to detect road anomalies in real-time in order to avoid traffic congestion and minimize accidents risk. As another example, in article [39], an approach to include Architecture Analysis and Design Language, Modelicaml, as well as Hybrid Relation Calculus was also introduced to developed big data-driven physical systems. The proposal was represented by a case study on VANET modeling.

2.2 CSC related works

The connected vehicles that could be considered as a complex cyber-physical system permit to visualize enriched car-related information digitally, to process data in order to improve the driving experience and to reflect driving behavior. Authors in [40] defined and identified the second dashboard as a device or application that allows extensions of the primary automotive experience on a second screen (e.g., smartphone or tablet). Accordingly, they specified information type that users are interested in and they detailed the second dashboard needs to create useful and innovative user-centered connected car services and applications. Their funding was based on focus groups interview's. The information they would like to see on a second dashboard are related to vehicle defects or damages, wearing parts, remote awareness and remote control, task list, financial issues, location-based information, environmental information including emission values, information relevant for driving or security and information for car-related management. Data analytics is important to advance CSC. In [41] authors studied design steps to implement Map Reduce patterns in order to analyze vehicle's data in order to produce accurate and useful knowledge through big data technology by collecting data sets uploaded from connected cars. The obtained knowledge merged with external information afford connected cars with new applications.

2.3 Autonomous driving related works

IoV has communications, intelligence, storage, and learning capabilities to anticipate the customers' intents. Vehicular fog will help the transition to the IoV and will provide the services required by the autonomous vehicles. In [42], authors discussed the evolution from intelligent vehicle grid to autonomous vehicle, IoV, and vehicular fog. Besides that, they considered that vehicular fog will be the core system environment for this evolution. The first step toward autonomous driving has begun with the Advanced Driver Assistance Systems (ADAS). This kind of feature is based, especially, in radar sensors that are able to scan the near car environment. To enable fully autonomous driving, the information from these sensors is insufficient in case of urban traffic situations. To overcome this issue authors in [43] proposed to add additional information (e.g., the exact location, speed, direction of the car, and the current traffic situation) based on High Definition (HD) maps which are known as a multi-dimensional information. In the same context, authors in [44] proposed a novel protocol called Cooperative Driving Control Protocol (CDCP), for intelligent autonomous vehicles. This protocol makes the autonomous vehicles have a common language to achieve cooperated intelligent driving with other vehicles, increase the reaction time before other vehicles perform some driving action, and decrease the average travel time at the same speed. To deal with the traffic oscillations caused by freeway merging, authors in [45] developed a cooperative intelligent driver model in order to examine the system performance under different proportions of autonomous driving. Finally, we refer that big data technology is contributing to the progress towards fully autonomous vehicles.

3 Automotive system evolution

In this section, we discuss the evolution from VANET toward IoV and CSC. Accordingly, we start by introducing the conventional VANET. Then, we provide basic concepts related to IoV as a powerful development in IoT framework following VANET. Finally, we present CSC as the future vehicle generation.

3.1 Vehicular AdHoc Networks

3.1.1 Fundamental Concepts

VANET supports ITS. VANET consists of a nearby vehicles network, which are fitted with sensors and communicate among themselves as well with fixed types of equipment usually described as RSUs. Thus, two main types of communications are established in VANET named as V2V, V2I or V2R communications (see Fig. 1). V2V communication approach uses multi-hop/multi-cast techniques and it is most suited for short-range vehicular networks (e.g., traffic signal timing adaption), while V2I communication provides a solution to longer range vehicular networks (e.g., route guidance). VANET applications are categorized into two major classes according to their primary purpose: (1) safety applications (e.g., collisions and accidents avoidance), (2) non-safety applications (e.g., comfort and entertainment activities). In order to perform VANET communications, different wireless communication technologies are used. The most predominant access technologies are Dedicated Short Range Communication (DSRC) and Wireless Access in Vehicular Environment (WAVE). DSRC standard is a short-range wireless communication channel that is based on IEEE 802.11p, and operates in the 5.8GHz or 5.9GHz wireless spectrum. WAVE is employed for 802.11 devices to operate in the DSRC band. It is mainly related to Medium Access Control (MAC) and Physical layer (PHY) protocols and corresponds to IEEE 802.11p, IEEE 1609.1-4 (defined respectively for resource management, security services and messages management,

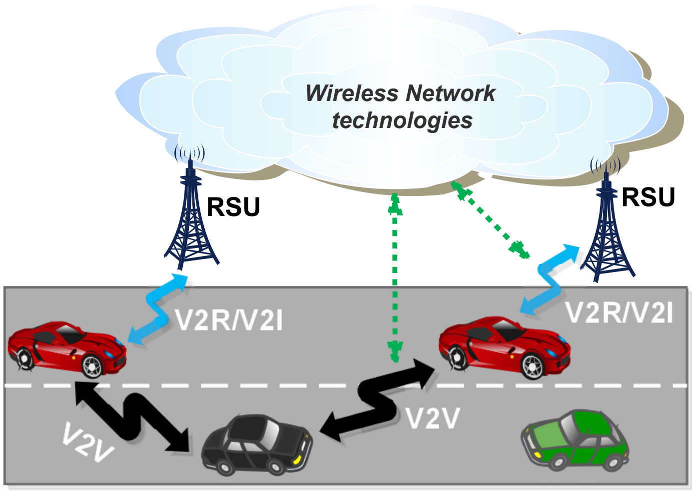

Fig. 1 VANET main communication types

networking services, and multi-channel operation), and SAE J2735 (Society of Automotive Engineers) protocols as shown in Fig. 2.

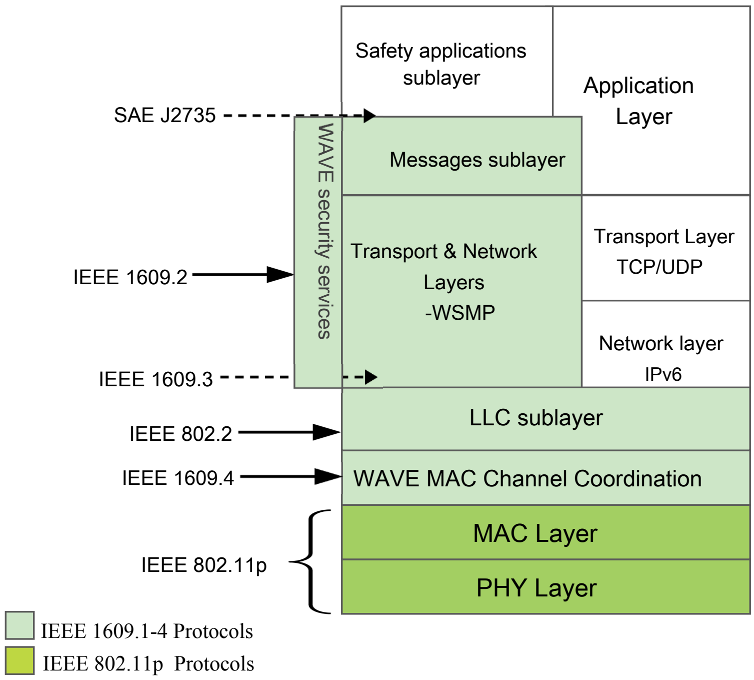

Fig. 2 Protocol stack for WAVE standard

3.1.2 Research challenges

Since VANETs are a subset of Mobile ad hoc networks (MANET), they inherit most of the characteristics of MANETs. However, VANETs possess some special characteristics including high mobility of nodes, dynamic network topology, stringent delay constraints, road pattern restrictions, frequent disconnections, infinite energy supply, no restriction on network size, and no power constraints [46]. Authors in [47] are performed studies to survey the potential of VANET according to the own specific challenges of communication area, for example by driving on the highway, in rural, or in urban scenarios. We provide in this section major faced challenges in the realm of vehicular communications. Hence, we refer briefly a few approaches that act as a catalyst in raising the key related challenges, as well as some recent dedicated survey papers. Table 2-4 summarize the main research challenges for vehicular networks. However, we determinate that over the past several decades, the desired commercial interests and the scaled deployment in the world of VANET have not emerged, that is subject to VANET limitations such as communication types[48], connection availability, network architecture, environment awareness, or within decision capabilities [49], cloud computing compatibility, collaboration capabilities, and scalability. Thus, VANET has involved into IoV.

3.2 Internet of Vehicles

In contrast to VANET, IoV promises advanced features with a significant extension over VANET capabilities. It supports many recent technologies such as cloud computing, big data, and data mining, as well as it provides service management with an exclusive and several services even for the whole country. In order to achieve exceedingly more smart applications, IoV is faced with several communication requirements, which are basically related to low communication delay, sufficient transmission distance, and high reliability under high-speed. From the literature related works, and especially according to [83], the common architecture design of IoV contains five layers namely (from lower to upper): perception layer, coordination layer, AI layer, application layer, and

Table 2 VANET research challenges

Research issues	Research issues	Ref./date	Approaches and main concepts	Limits
	Based cloud	[50]/2015	Vehicular cloud computing model (named VANET-Cloud), that consists of client, cloud, and communication layers, to support and provide access to computing resources and cloud services.	Maintaining security, interoperability, and standardization
VANET architecture		[51]/2017	Survey paper that investigated the vehicular cloud paradigm challenges, with focusing on its features and architectures. The survey suggested also a classification of vehicular cloud that consists of architecture, management, and services axes.	none.
	Based SDN	[52]/2018	Architecture that combines the RSU and the cellular networks, to support the QoS requirements.	-Changing RSU has an impact on performance in term of Packet Delivery Ratio (PDR). -Only two metrics were considered: Round Trip Time (RTT) and PDR.
		[53]/2020	Survey paper that exposed the advantage of SDNs in building a reliable VANET frameworks, with elaborating the major challenges which need to be solved along with such SDN-based VANET architecture.	none.
		[54]/2019	Survey paper that presented the challenges faced by SDN-based vehicular architectures from QoS and scalability perspectives.	none.
		[55]/2019	Survey paper that discussed the significant issues in the large scale deployment of SDN-based VANET architectures.	none.
	Hybrid approaches	[56] 2017	Approaches that combine CCN, Floating Content (FC), and SDN for enabling VANET, to disseminate efficient messages and VANET regardless of fluctuating node density, mobility patterns, and intermittent connectivity.	-CCN and FC should be adapted, to the highly dynamic and volatile network environment. -SDN cannot provide dynamically configured routes at each hop.
VANET mobility	Based FC+HR	[57]/2018	Approach that adapts FC and Home Repository (HR) concepts as a solution for source mobility in vehicular-NDN, to increase the efficient content delivery probability.	-Risk of a content unavailability within a certain region with an extremely low vehicle densities scenarios.
	Based SDN	[58]/2017	Routing protocol (named SVAO), to enhance the data transmission efficiency, by redesigning the network control and the data transfer layers.	-Performances depending on the density of nodes and the vehicle velocity: an obvious decline in performances with scenarios under high speed conditions.

Table 3 VANET research challenges (continued)

Research issues	Research issues	Ref./date	Approaches and main concepts	Limits
Routing in VANET		[59] 2020	Survey paper that highlighted the requisite perspectives to improve the development SDN-VANET of in terms of routing protocols.	none.
	Based ICN	[60]/2017	Content routing forwarding scheme (named RSBLQ), to minimize network delay, cache hit ratio, and network traffic.	-Constant vehicular parameters: Factors such as complex road topology, traffic lights, and RSU were not taken into account. -More link quality metrics should be considered.
		[61]/2017	Routing protocol that adapts NDN and that is based on Auxiliary Forwarding Set (AFS) mechanism, to mitigate the probability of delivery content prevention.	-An increase of forwarding delay in scenarios with a content provider placed in large distance.
	Natural inspired Swarm Intelligence	[62]/2017	Routing protocol (named Ant-AODV-VANET) based on Ant Colony Optimization (ACO) algorithm, to find the optimized path from source to destination (with lesser number of hops and high link quality).	-Performances depending on the distance between nodes and the hop count: better result with a short distance and a small number of hops. -More characteristics of VANET should be considered.
		[63]/2017	Approach that introduces the fractional glowworm swarm for TAR VANET routing protocol, to search the optimal routing path (with minimal delay, distance, and traffic density).	-More metrics should be considered such as the multiple constraints, packet delay, and link lifetime.
		[64]/2015	Routing protocol (named PP-AODV) based on Q-learning algorithm, that uses AODV routing to enhance packet delivery ratio and reduce end-to-end delay.	-Simulation under vehicles speed with 25-40 m/s.
		[65]/2014	Routing algorithm based on congestion game, to provide the optimal path.	-Forwarding performances depending on the number of gateways installed on the route.
Security in VANET	Attacks types + solutions	[66]/2017	Attacks types and detection mechanisms in VANET.	-High inclination toward defense mechanisms based on modeling. -Simulations were neglected.
		[67]/2017	VANET vulnerabilities, security requirements, and future research direction.	-Very limited analysis of VANET vulnerabilities.
	Based SDN	[68]/2016	SDN impact analysis within real uses cases (smart parking, smart grid of electric vehicles, platooning, and emergency services).	-Security threats in SDN-enabled VANET such as software vulnerabilities, single point of failure, and flow-poisoning attack.
	Based Blockchain	[69] 2020	Survey paper that outlined the key open issues where Blockchain is applied in IoV and vehicular cyber-physical systems.	none.
		[70] 2020	Survey paper that reviewed the specific challenges facing the Blockchain application to 5G-enabled vehicular networks.	none.

Table 4 VANET research challenges (continued)

Research issues	Research issues	Ref./date	Approaches and main concepts	Limits
	Game theory	[71]/2018	Approaches comparison(characteristics and behaviors).	none.
	Authentication	[72]/2018	Authentication scheme (named CIAS) based on asymmetric encryption, to assist V2I and inter RSUs authentications	-None.
	Data integrity	[73]/2018	Fuzzy logic based scheme (named FL-CFT), to ensure file integrity transfer.	-The impact of the file size on scheme performances should be addressed.
	Trust management	[74]/2018	Secure framework (named SEGM) for group management (setup and maintenance, access authentication) in integrated VANET-Cellular networks.	-Security for mobility management group was not considered.
		[75]/2015	Research that address trust management in VANET.	-Trust based solutions for VANET were not introduced.
	Attacks detection mechanisms	[76]/2017	Spoofing attack approach in vehicle location verification (named MHLVP).	-Dissatisfaction result for the network bandwidth consumption. -Risk of network topology damages. -A secure system for detecting attacks from unauthorized vehicles should be taken into account.
		[77]/2017	Algorithm to detect DOS attack, by using Secured Minimum Delay Routing Protocol.	-Simulation with different scenarios such as highway and rural environments should be taken into account.
QoS improvement in VANET	End-to-end delay minimizing	[78]/2017	Access selection algorithm (named ORAS), to accomplish low packet delivery delay, by increasing transmission link stability and decreasing the number of hopes per route.	-Connection time to RSU was not considered.
	Throughput enhancement	[79]/2017	Distributed MAC (named (DMAC) to reduce collision and data access cost, and maximize throughput.	-Performances in terms of reducing collision, improving packet transmission, and throughput depending on environment zone (rural, highway, urban). -An evaluation under conditions such as varied mobility speed should be realized.
		[80]/2020	Radio propagation path loss model that takes into account the impacts of the vehicle on line of sight I V2V environment.	none.
	Fairness allocation	[81]/2018	Algorithm (named MFCR) based on the concepts of multi-hop Pseudo Bayesian (PB) and single-hop Fast Conflict Resolution (FCR) algorithms, to solve time slot utilization and fairness allocation problems.	-Performances depending on the number of nodes(from 20 to 60).
	Real-time constraints	[82]/2015	Algorithm for real-time path-planning to avoid traffic congestion and enhance real-time communications.	-Evaluation under scenarios with a large-scale vehicle traffic was not realized.

business layer. Correspondingly, perception layer is responsible for data gathering and electromagnetic transformation of perceived data, by using various technologies such as Radio Frequency Identification (RFID), Global Positioning System (GPS), etc. Coordination layer works as a virtual universal network module to ensure interoperability. AI layer is designed as an information management center that mainly includes vehicular cloud computing [84], and big data Analysis. Finally, the major responsibility for application layer is to provide smart services, while the main functionality of the business layer is to foresight strategies for business models (see Fig. 3).

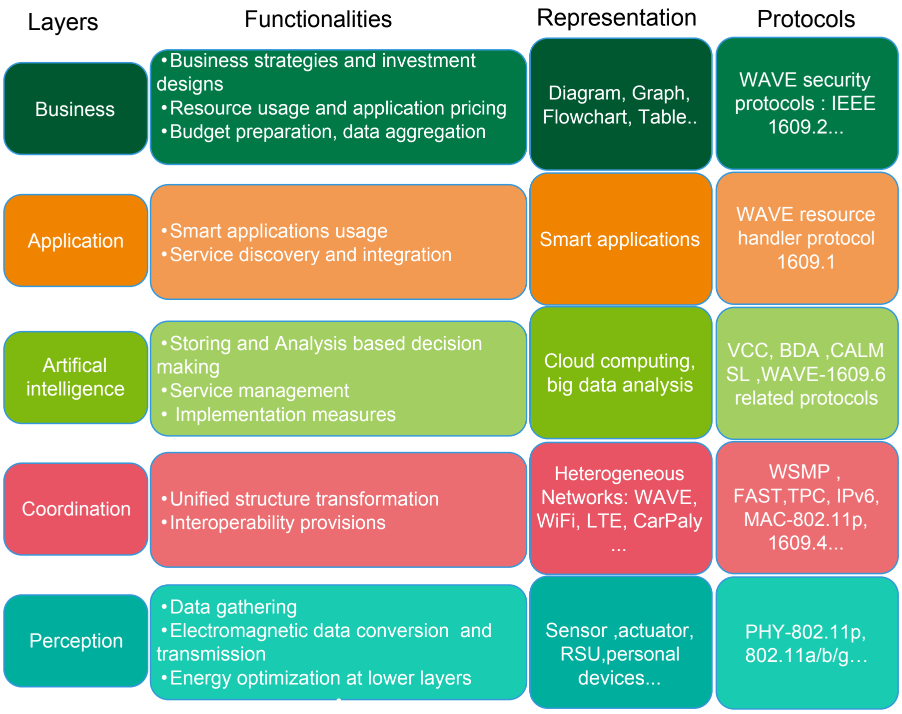

Fig. 3 Layered IoV architecture and protocol stack

However, while IoV promises advanced features, these could bring fundamental challenges. AI protocols are considered as a challenge in IOV due to the current unavailability of suitable protocols for vehicular cloud computing [85]. Authors in [86] specified that the business model for the business layer is a challenge for IoV. Security protocols for IoV are an open research challenge [87]. The perspectives of challenges in IoV are from multi-user, multi-vehicle, multi-thing, and multi-network [88]. Authors in [3] described localization accuracy, location privacy, location verification, radio propagation, and operational management as challenges for IoV. Other open challenges in IoV such as communication ability enhancement, sustainability of service providing assurance, disruption reduction, and disruption reduce are also applied. Due to the several novel features of IoV in vehicular communications, connected smart cars are the brightest evolution.

3.3 Connected Smart Cars

Wireless technologies evolution allow researchers to create new communication systems between vehicles to facilitate the communication and increase the road safety [89] [90] [91]. By this way, CSC defines a set of vehicles that cooperate with each other in order to exchange common services through wireless communication. The work proposed by authors in [89] highlight the importance of connected vehicles. In fact, the proposed a new architecture scheme that provides a better network management in smart and connected vehicles for safety and efficient decision. Last years, smarts cities include intelligent traffic management which must be reachable from and at any access point. To overcome this issue, authors in [90] proposed a new warning system that transmits traffic information in order to help the driver to take the appropriate decision. Particularly, this new framework provides information to drivers about some problems; for instance: weather condition and traffic density in the cities environment. In the same context, researchers in [91] proposed a new smart parking scheme for large parking lots through smart vehicular communication. This scheme aims to provide the drivers with real-time parking navigation service, intelligent anti-theft protection, and friendly parking information dissemination. Simulation results demonstrate the efficiency of this scheme compared to the related state of the art.

4 IoV communication system

In this section, we describe the main functions of the proposed communication system that allows IoV communication for autonomous driving as shown in Fig. 4. In fact, our system is divided into three principal zones: (i) Car-zone, (ii) Cooperative Zone that includes Vehicle-to-Everything (i.e., V2X) communications; where $X \in$Vehicle, Infrastructure, Human, etc., as well as vehicle to cellular communications, and (iii) smart city zone. To enable connectivity, communication, and data exchange among these three levels, in-car gateway plays an important role to share/gather network information through the Internet. These parts are described in details in the following sub-sections.

4.1 Car zone

The car zone has two main parts: (i) Environment sensing that involves several input components like Cameras, GPS, Wireless Fidelity (WIFI), etc., which contain rich data concerning speed, temperature, lights, tire pressure, load level, driver attentiveness, pavement condition, etc., and (ii) Intra vehicle networks where several electronic applications are installed. These applications are implemented by adding a new Electronic Control Unit (ECU) as shown in Fig. 5.Applying sensor fusion, various sensors inputs and sensor types are combined to perceive the environment, they can further be divided into two categories: (i) Proprioceptive sensors which are responsible for sensing the vehicle's internal state, and (ii) Exteroceptive sensors which are responsible for sensing the vehicle's surroundings. Currently, ECUs are widely used in vehicles for controlling and achieving most functions (e.g., collision control, engine control, Lighting system (interior and exterior) control, etc.). The information exchange through ECUs occurs through the use of communications protocol. In this case, bus-based networks are used to connect multiple ECUs such as Ethernet, Controller Area Network (CAN), FlexRay, low-bandwidth networks (LIN), and Media Oriented Systems Transport (MOST). In a real car, the contents of CAN messages depend on the car's designer but the form of these messages obeys a particular standard (ISO 11898), while the manipulation of the vehicle is carried out by the actuators.

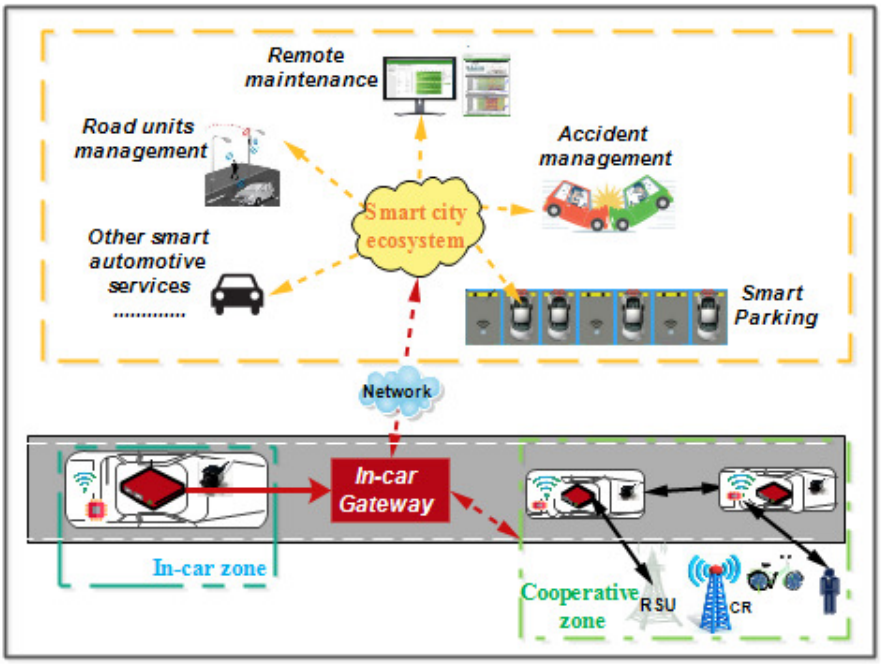

Fig. 4 Communication system

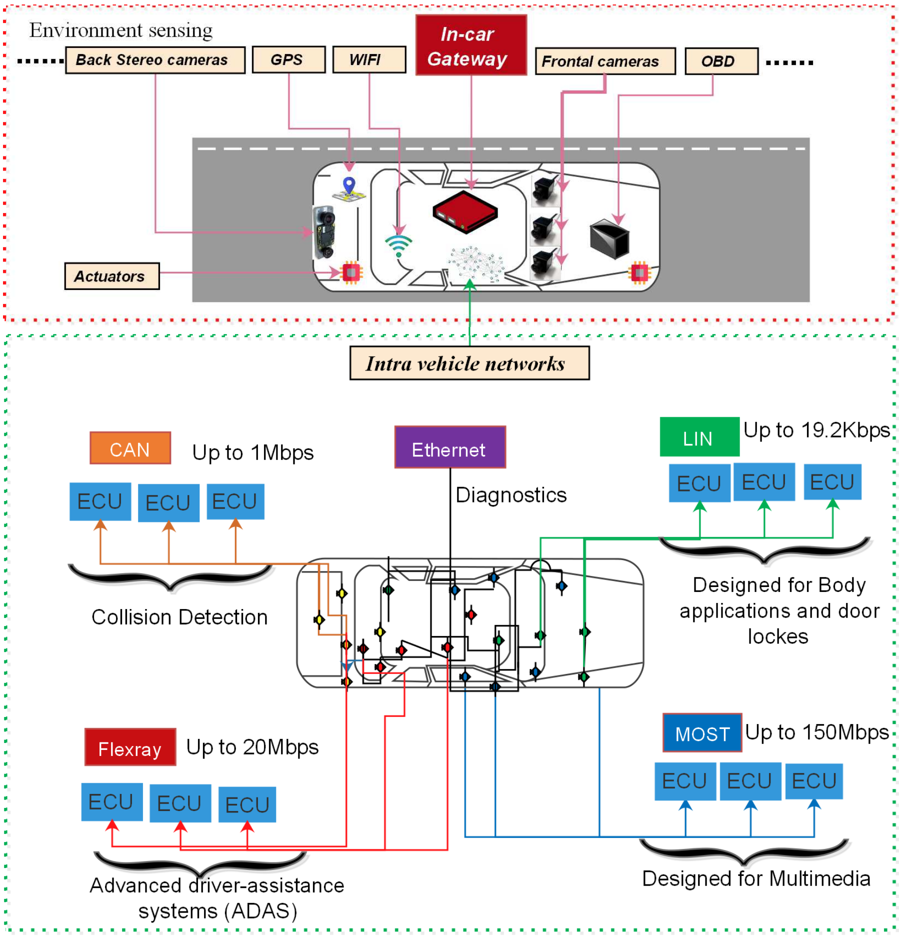

Fig. 5 Car Zone

4.2 Cooperative Zone

The implementation of cooperative systems for communication of vehicles with roadside infrastructures and users offers a wide range of efficient and beneficial cooperative services that provide real-time information which helps for traffic flows optimization, congestion reduces, accident numbers minimization, etc.. Accordingly, various communication types that mainly classified as V2X and V2C communications are performed. Fig. 6 depicts the different communications types into the cooperative zone.

4.2.1 Vehicle-to-Everything communication

Vehicle-to-X refers to an intelligent vehicle technology that incorporates specific communication types such as V2V, V2I, V2H, V2S, V2N, as well as

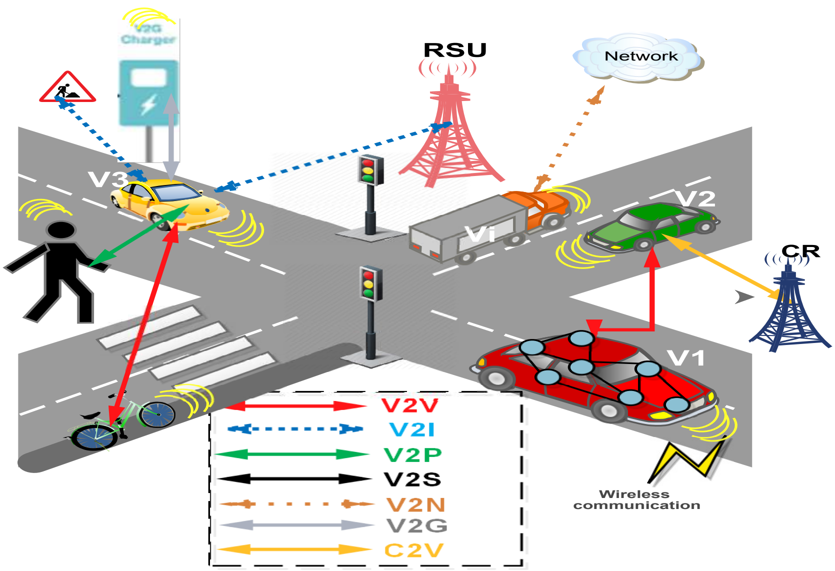

Fig. 6 Cooperation zone: Vehicle communication types

V2G and enables vehicles to cooperate with each other and their surroundings through 802.11p/DSRC based wireless technologies, by passing signals and messages regarding road conditions (e.g., traffic congestion, traffic signal timing, pedestrian in walkway, real-time traffic, etc.). We consider a set of i vehicles (denoted $V_i = V_1, V_2, V_3, \ldots, V_i$) moving within an area. We assume that each vehicle at any place i can communicate with α vehicles; $\alpha \in [0, N]$. The enhanced distributed channel access is used as the MAC protocol of the IEEE802.11p standard which is an enhanced version of the basic access mechanism in IEEE 802.11 using QoS. Each vehicle V_i not only transmits the packets generated at its own application layer (i.e., its own sensing environment), but also forwards the packets arriving from other vehicles located in its transmission range (i.e., at least one-hop neighbors).

4.2.2 Cellular-to-Vehicle communication

V2C is a promising wireless communication technology released within the 3rd Generation Partnership Project (3GPP), which builds on the growing cellular links rates to achieve V2X communications, leveraging enhanced Long-Term Evolution (LTE) connectivity and advanced 5G mobile network. Cellular V2X defines two complementary communication modes: (i) direct Device-to-Device (V2V, V2I, and V2P) communications, and (ii) V2I communications. Besides, it brings improvements over 802.11p that offer enhanced vehicular services like efficient transmission structure, safer driving experience, increased situational awareness, reliable support for high speeds, and more robust internet connections. The evolutionary path to 5G address expanding mobile wireless networks capabilities needs and quality of service guarantee, which ultimately lead to strong smart cities ecosystem support. The 5G network has achieved meaningful reach by 2020. It promises CSC and fully autonomous driving proliferation that crunch through terabytes of data per car every day since it is a key solution for providing an extreme variation of requirements such as ultra-reliable networks, low-latency, and an 'always-connect' for road users.

4.3 Smart city zone

A smart city involves the intelligent use of technology to improve how people live, work, commute and share information. Citizens engage with the smart city ecosystem by using a variety of ways such as smartphones and smart devices interfaces. Currently, smart cities are expanding quickly owing to the wildly innovative IoT solutions. These related proposals mostly comprise advanced platforms based on the aforementioned promising technologies (e.g., Cloud, ICN, SDN, and Blockchain) that hold the huge amount of required data and enable information accessing and forwarding while maintaining efficient performance across the various types of devices [92]; including cars. CSC and autonomous cars will live on a large scale and play a central role in the innovative automobile industry within the smart cities of the future. Actually, the move towards autonomous cars in smart cities promotes increased safety driving and better environmental conditions (e.g., by reducing unnecessary fuel consumption). Within an IoT ecosystem vehicles are capable to exchange real-time data from many ECUs, traffic lights sensors, cameras, parking meters, road sensors, etc., which means that a pervasive and a reliable wireless connectivity block (e.g., 5G network) is fundamental to reach full vehicles potential. For example, trains and buses pass real-time information about their location, driver and carrying passengers number to public transport users, which allows public transport fleets to improve their operations. Thereby, several smart cars services are available ranging from smart parking, remote diagnostics, charging support and energy storage for the electric car, to charges and fees, accident management, emergency assist, bottlenecks alerts, traffic lights adaptation, lane changing, smart traffic signal's and vehicle traffic regulator's communications, trip cost estimation, passenger ticketing, etc.. Fig. 7 describes automotive services components within the smart city.

5 In-car gateway architecture

With the highly dispersed nature of the smart city ecosystem and the cooperative zone, as well as the scores of the connectivity modules, gateways are needed to manage and control these complex environments. However, to the best of our knowledge and according to the above referred works, research activities emphasis on three main approaches models: (i) Designing gateways to maintain communication between intra-vehicle networks, (ii) Designing gateways to maintain communication between intra-vehicle and V2X networks, (iii)

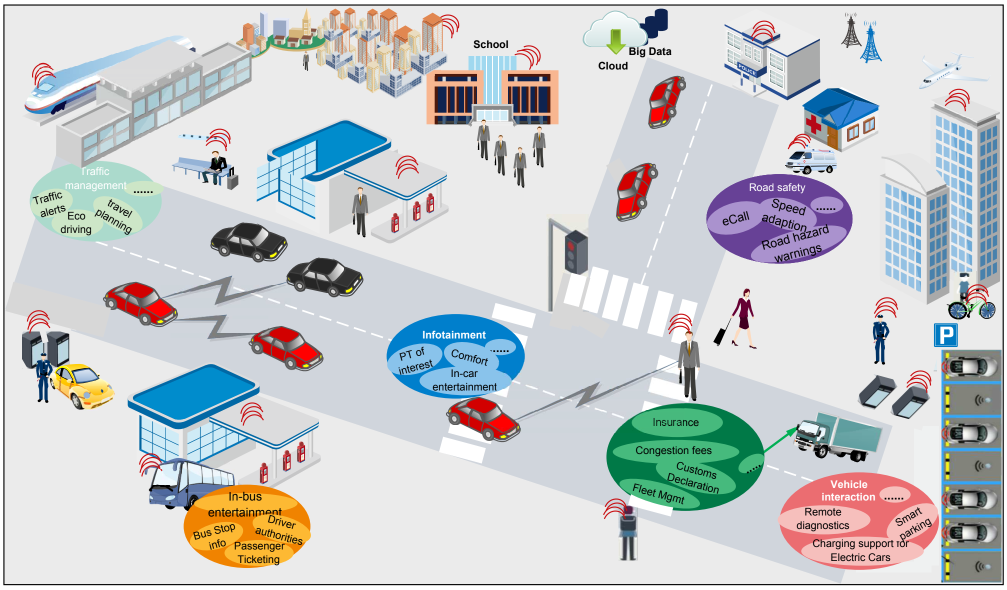

Fig. 7 Smart city ecosystem

Designing gateways to maintain communication between intra-vehicle and cellular networks. As a result, no work has established a coordinator (i.e., central gateway control messages) in order to mediate the communication between these three zones and support the interoperability among the involved devices. Accordingly, in this section, we specify an in-car gateway as a bridge that enables the three aforementioned zones to 'talk' with each other. Our proposed in-car gateway architecture would be adapted to the autonomous driving specific needs. It discovers and connects devices, as well as aggregates, identifies, converts, process, filters, analyzes, and shares collected data from those devices. It also provides devices connectivity by involving wireless backhaul modules and V2X network interfaces, and ensures that data can travel securely and safely from the edges to the cloud. Fig. 8 depicts a high-level overview of the in-car gateway architecture. In order to fulfill the required specifications for the in-car gateway, we need to specify the hardware and the software structures. In fact, the hardware structure consists of three main parts, which are: (i) The Central Processing Unit (CPU), (ii) The storage module, and (iii) The Input/Output interfaces; whereas the software structure is geared to the AUTOSAR's related basic software architecture that distinguishes between three main layers which run on a microcontroller: (i) Application Software layer, (ii) Runtime Environment (RTE) layer, (iii) and basic software layer [93]. It comprises the user level which is referred to the autonomous driving application and the system level. In the following, we provide a description of the hardware and software components and their design model.

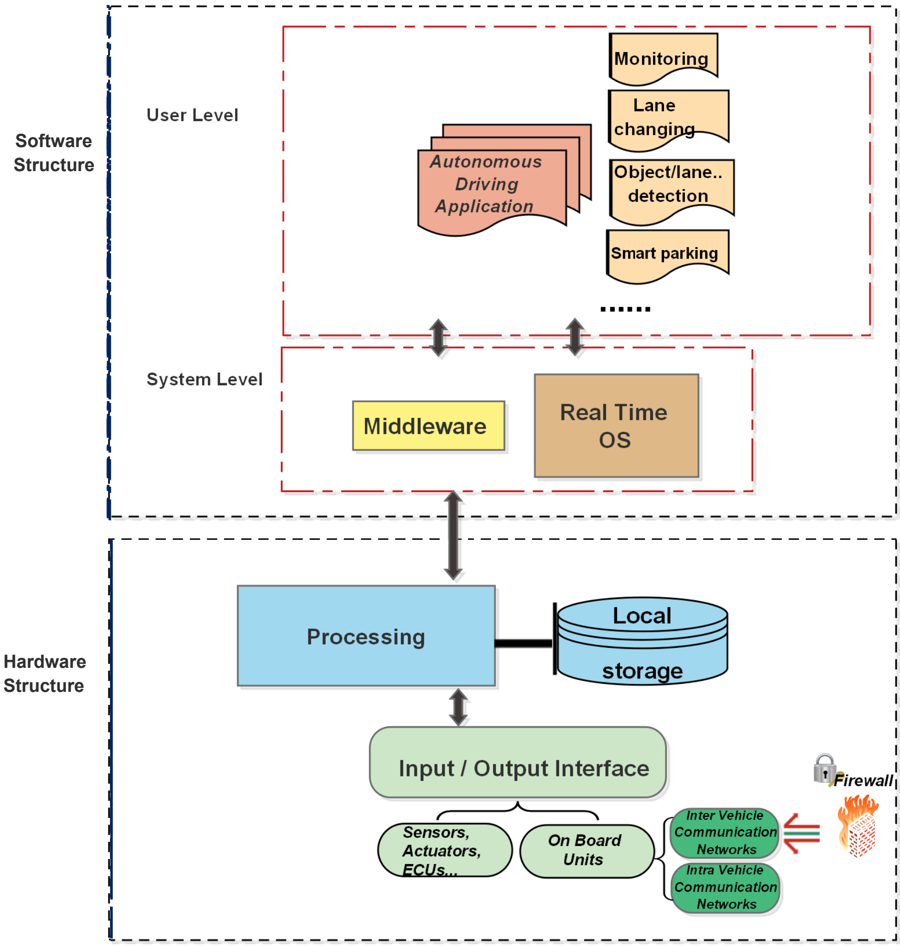

Fig. 8 In-car gateway global architecture

5.1 Hardware Design

The in-car gateway hardware structure is illustrated in Fig. 9. The environmental model involves IoV communication system and smart city ecosystem, where several RSU, vehicles, pedestrians, and other roadside users (e.g., roadsters) interact with the in-car system by using 8.2.11 network technologies and mobile wireless backhaul modules. The CPU and the data storage model are required to handle low-level tasks, carry out commands (e.g., fetching, decoding, executing, Writing-back, ...), and meet digital storage needs. ARM STM32F2 CPU, NVIDIA Drive PX2 CPU, ELM327 CPU, and so on, that support respectively CAN; UART; SPI, Ethernet, and OBD-II protocols can be employed in this context. The inter-vehicle networks have communication interfaces with other in-vehicle networks and devices through Input/Output

CPU ports (e.g., OBD-II, GPIO, USB, etc.). Furthermore, the architecture uses the firewall as a mechanism for secure onboard communications. The in-vehicle buses that combine usually LIN, CAN, FlexRay, MOST, and Ethernet are intended to integrate, exchange, coordinate control, and transfer functions, data, and messages within the car. Accordingly, MOST is used to enable high-quality vehicle multimedia components interconnection, FlexRay is applied to provide a high reliability and speed network, Ethernet is prominent for connection control units diagnostics, while LIN and CAN are needed for instance to ensure a low power consumption. Besides, multiple actuators and sensors such as cameras, LIDAR, radar, and ultrasonic sensors are installed to prevent human interaction. Sensors are necessary to allow the vehicle to understand accurately the full 360-degree surround environment, they will activate the various actuators which will execute autonomously the target actions like locating free parking spaces, planning a safe path forward, unlocking a door, etc.).etc.. Furthermore, many Electronic Control Units (ECUS) for engine, body, chassis, etc., are integrated to sustain ADAS, provide various functions for autonomous driving, such as low speed car passing, auto lane changing, traffic jam assist, etc., as well as to perform frame formats mapping between the different bus architectures.

5.2 Software Design

The software structure for the in-car gateway is depicted in Fig. 10. The user level is represented by the typical autonomous vehicle system highlighting its basic components, which consist of perception, planning, and execution layers with their required device interfacing software components (e.g., GPU accelerator, media player, etc.). The perception layer collects environmental data and extracts relevant information. The planning layer is responsible for understanding the gathered meaningful information in order to make purposeful decisions about its actions, while the main functionality of the execution layer is to control and achieve the intended actions (e.g., path tracking, accelerating, etc.). These functions are explored in details in the following section. The system level is depicted mainly with a Real-Time Operating System (RTOS), a middleware, and standardized interfaces. RTOS is applied to provide, manage, and adhere to the complex tasks deadlines such as scheduling, system clock functions, memory management, task-state switching, device drivers, error handling, application security, etc. The middleware is required to provide adequate abstractions for the different dynamic application services from their proprietary interfaces that integrate heterogeneous smart devices, and different sensor network technologies with the cloud platforms. It can also offer a set of complimentary services and tools to support and sustain the management of resources like Content Adaption Framework (CAF), MirrorLink Client, etc.. In order to emphasize software exchange and reuse, as well as facilitate the encapsulation of the different functional software components, the

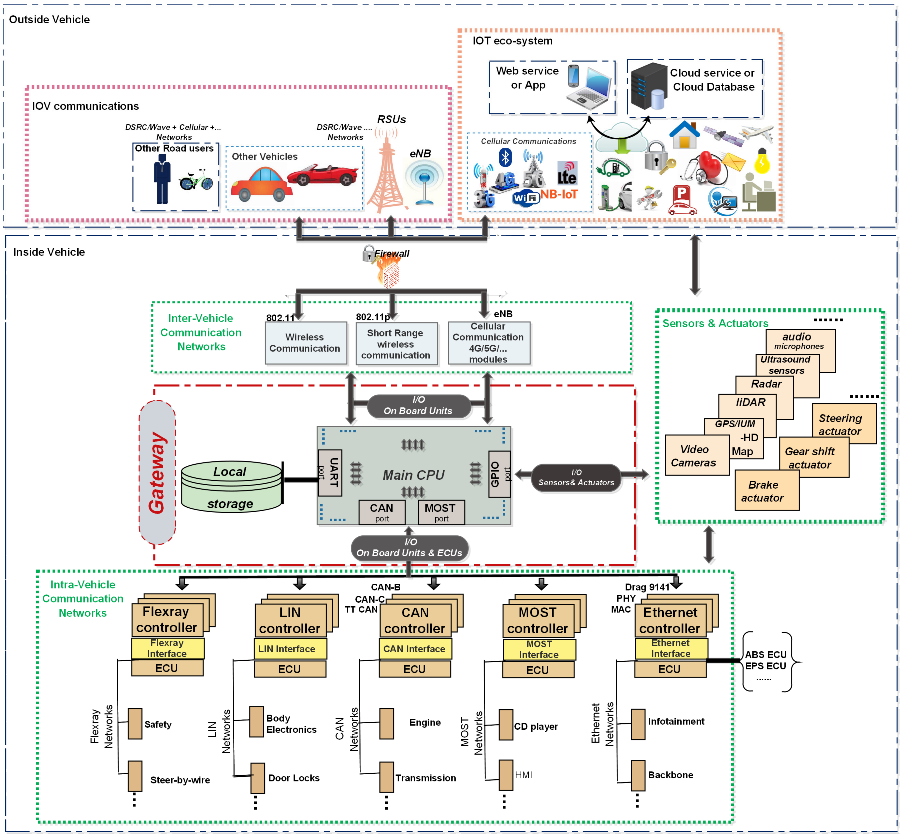

Fig. 9 In-car gateway hardware architecture

software design is predicated on the standardized interfaces and Application Programming Interfaces (API).

6 Information flows for Autonomous driving Service

In this section, we highlight information flows for autonomous driving service delivery. For this purpose, basic self-driving functions should be specified such as (a) perception, (b) planning, and (c) control and execution. Then a lane changing process is offered for autonomous driving.

6.1 Perception

Perception in autonomous vehicles is the ability to create and interpret an emerging environmental model with a collaborative situational awareness to safely and independently conduct a self-driving vehicle by making self-informed

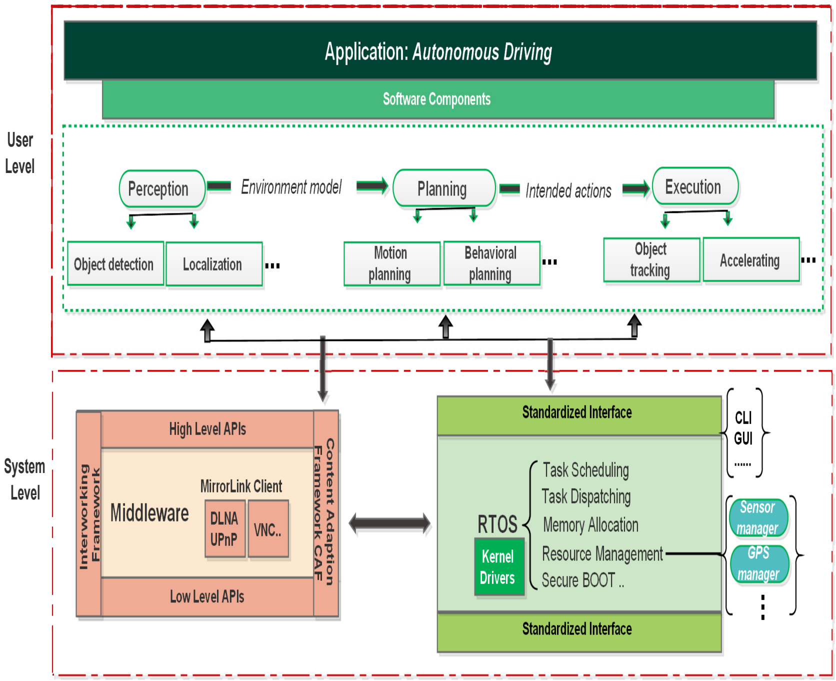

Fig. 10 In-car gateway software architecture

predictions and actions. Perception mechanisms enable many services for autonomous cars, however, we emphasize in this subsection on object detection service.

– Object detection

The object detection is a key task for bounding, describing, and recognizing the location of every class object (e.g., trucks, bicycles, road signs, pedestrians, etc.). It is mostly the domain of sensors. Many contributions have been introduced in this context like [94], [95], [96], [97] and [98], as well as several algorithm models were adopted such as YOLO, Fast R-CNN, OverFeat, and SimpleNet [99]. In order to reliably identify objects, the object detection subsystem has an interface towards various sensor input devices that includes a wide set of cameras (e.g., driver rear view camera, passenger rear view camera, wide forward camera, stereo camera, driver surround camera, etc.), GPS-IMU, LIDAR, RADAR, and others. Accordingly, related sensors managers are executed over the in-car gateway's kernel. The camera sensor is used to produce effectively visual streams with a texture, color and contrast information, it plugs into the CPU USB port. The camera manager is responsible for the remote control of the camera and the videos and photos process, while the GPS manager has the responsibility of knowing object position and time mark. In this way, the in-car gateway captures images from the stream, hereafter attached temporal and spatial coordinates from the GPS manager are applied to the content. Later, the camera manager uses for intended libraries, to analyze them and perform for example road users classification for keeping a safe distance after calculating their speed by using the GPS position. It can also capture small video fragments and send them to the cloud. LIDAR sensor uses laser light to enable high precision detection of smaller objects in real-time by building near perfect 3D monochromatic images of car's surroundings objects, and to measure objects distance, while Radar sensor is used for performing objects motion prediction, as well as speed, range, and angle detection. Compared to LIDAR, Radar sensor has limited small object detection precision, although it can be used in cloudy weather.

6.2 Planning

Planning is essential for self-driving cars to make a purposeful decision based on the perceived surroundings. The planning task is achieved by AI and algorithms. It handles significant methods like path planning to determinate the optimal (i.e., safe, comfortable, and efficient) route, behavior-aware planning to properly interact within the cooperative zone, motion planning to process appropriate actions such as path planning, obstacles avoidance, etc.

– Motion planning

The motion planning for autonomous driving is a central challenge. A range of different methods and approaches have been proposed in this area such as approaches in [[100]-[105]]. The self-driving vehicle's decision making sub-system uses information about its current position as well as obstacles localization and orientations, to generate for example the best road route by using classical algorithms like Dijkstra algorithm. The behavior planning and the collision detection algorithms are applied, thus the autonomous car would be able to navigate the planned route according to the road rules and the perceived behavior of other road users with the sensor fusion. For instance, if a traffic signal such as stop line is reached, a car that suddenly changes lane, or a pedestrian who suddenly stop midway during a road cross, the in-car gateway will apply the motion planning algorithm, performs the speed control system (current speed, safety distance, new speed limit, etc.), and activates the linear actuators which in turn, will use CAN bus to apply brakes and switch off the engine until the lights go green, or slow down until pedestrians take the foot-ways.

6.3 Control and Execution

The control and execution concepts consist of sending commands and control inputs to processors and actuators, to generate orders to timely and safely executing each planned decision on the road such as steering, trajectory tracking, changing gears, and applying brakes.

– Steering control

Steering concept is a requirement for autonomous driving to improve safety and control. In this context, four options can be distinguished: (i) Protectionist (i.e., the vehicle protects passengers at all costs), (ii) Humanist (i.e., the vehicle tries to minimize the amount of injury), (iii) Altruistic (i.e., the vehicle prioritizes pedestrians above its occupants), and (iiii) Random (i.e., the vehicle behaves equally to the instinctive driver reactions). The steering unit has a standardized interface that works with GPS steering systems via CAN bus. For example, the self-driving car is about to drive straight across an intersection with a cyclist up ahead, sensors will detect nearby road conditions and users behaviors (e.g., vehicle approaching, edges locations, etc.). Accordingly, the planning layer predicts cyclist movement orientation and plans for braking. Through the steering actuator, is possible to draw the steering wheel in search of the most suitable position to make room for the cyclist to pass safely.

6.4 Autonomous Driving use case: lane changing

In this subsection, we present an autonomous driving process for lane changing along a highway zone (with two lanes road)(see algorithm 1). The algorithm uses the following functions:

- AppV in CrL: Approaching Vehicles in Current Lane
- FV SD: Front Vehicle Slow Driving
- FrL: Free Lane
- NOverV: No Overtaking Vehicle
- ESSpace: Enough Safety Space
- InfoWarLaneC: Information Warning for Lane Change
- SpeedControlProc: Speed Control Procedure
- SteeringControProc: Steering Control Procedure

Three basic phases, that constitute our process, are described below:

- Phase 1: Lane recognition

The lane recognition is one of the essential functions that is required to identify lane marks, boundaries, road edge, angles, slopes, curbs, berms, etc., as well as to extract the target lane features that comprise different information such as width, length, color, gradients, etc. It depends on many factors like the various types of marks (i.e., dashed, solid, etc.), the different weather (i.e., snow, rainfall, etc.), and the change of light conditions (i.e., shadows, glare, etc.), which implies the use of advanced perceptive sensors. Accordingly, the general process of lane detection involves data collection, pre-processing, feature extraction, and lane modeling.

- Phase 2: Surrounding traffic assessment

The surrounding traffic assessment phase is based on all the safety-perceived information such as relative position inputs, acceleration inputs, steering inputs, etc., which are shared through the in-car gateway via the vehicular communication networks, and taken as indicators for the safe lane changing decision. Vehicles positions are derived from the GPS receivers and vehicles speeds are obtained from the speed sensors. Other several sensors like LIDAR, RADAR, video-based sensors are accurately applied to receive imaging data and detect closest vehicles within the driving zone. All these information are available via the inter-vehicle data buses, processed through the in-car gateway CPU (e.g., steering angle encoder), and distributed across the actuators in order to execute the desired task.

Algorithm 1: General process for lane changing decision

```
Input:
Alg_i: ith vehicle Longitudinal Acceleration
Alt_i: ith vehicle Lateral Acceleration
Vlg_i: ith vehicle Longitudinal Velocity
Vlt_i: ith vehicle Lateral Velocity
Plg_i: ith vehicle Longitudinal Position
Plt_i: ith vehicle Lateral Position
S: subject vehicle steering angle
List_F: target lane features
Output: Lane change trajectory
if (AppVinCrL) ∨ (FVSD) then
    if (FrL ∧ NOverV) ∨ (ESSp ∧ NOverV) then
        InfoWarLaneC();
        Generate(tend);
        // Assumed time to complete lane changing
        Initialize t=0;
        while (t < tend) do
            USpeedControlProc(Vlg,Vlt,Alg,Alt,Plg,Plt);
            // Performing adaptive speed control algorithm
            USteeringControProc(S,List_F,angerror,laterror);
            // Performing adaptive steering control algorithm
            Compute(t);
            // time assumptions to complete lane changing operation
    else
        if Non(NOverV) then
            Wait for following vehicle to overtake;
        Slow down and braking;
```

– Phase 3: Lane changing decision

To make the lane changing decision, two general cases are performed: (1) When rear vehicles are approaching quickly, and (2) When the front vehicle is driving slower than the limit speed. To study these two cases, let's consider a scenario formed by a subject vehicle, leading vehicle and following vehicles in the current lane, adjacent, leading, and following vehicles in the adjacent lane, denoted by V_1, V_2, V_3, A_1, L_2, and F_3, respectively (see Fig. 11). If the leading vehicle in the current lane (i.e., V_2) is moving very slowly, or in case of rapidly speeding up and approaching of the following vehicle in the current lane (i.e.,

V_3), the subject vehicle V_1 will make the decision for moving to the adjacent lane. After guaranteeing the availability of required safety spacing between the subject vehicle V_1 and its surrounding vehicles (i.e., V_2, V_3, A_1, L_2, and F_3), and checking that there is no overtaking vehicle (i.e., V_3), or realizing that the contiguous lane is free (i.e., A_1, L_2, and F_3 GPS information's are not detected), the appropriate algorithms for speed and steering control that are based on considered vehicles datasets, will be generated to formalize safety distances, readjust adapted velocity, and decide desired steering, for enabling the subject vehicle V_1 to navigate safely the neighboring lane. Otherwise, the decision for slowing its current velocity will be executed. Furthermore, it is required to ensure that the lane changing operation is completed in the interval ranging from 0 to tend. Fig.12 identifies the information flow during the general process of the lane changing decision.

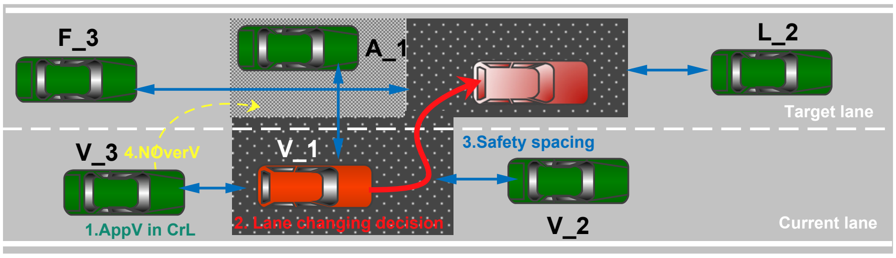

Fig. 11 Lane changing scenario

7 Conclusion

In this paper, we proposed a communication system that involves three zones: car zone, cooperation zone, and smart city zone, in order to allow IoV communications. For this purpose, we specified an in-car gateway architecture that enables communication and data exchange among these three zones. The hardware and software structure of this in-car gateway was introduced. Our proposed architecture is innovative, it could support several advanced services such as autonomous driving. Therefore, we highlighted basic functionalities and information flow for autonomous driving service in the previous section. Furthermore, we proposed an autonomous lane changing process to support our proposal. In future work, we plan to implement our gateway within the intended network to validate its efficiency.

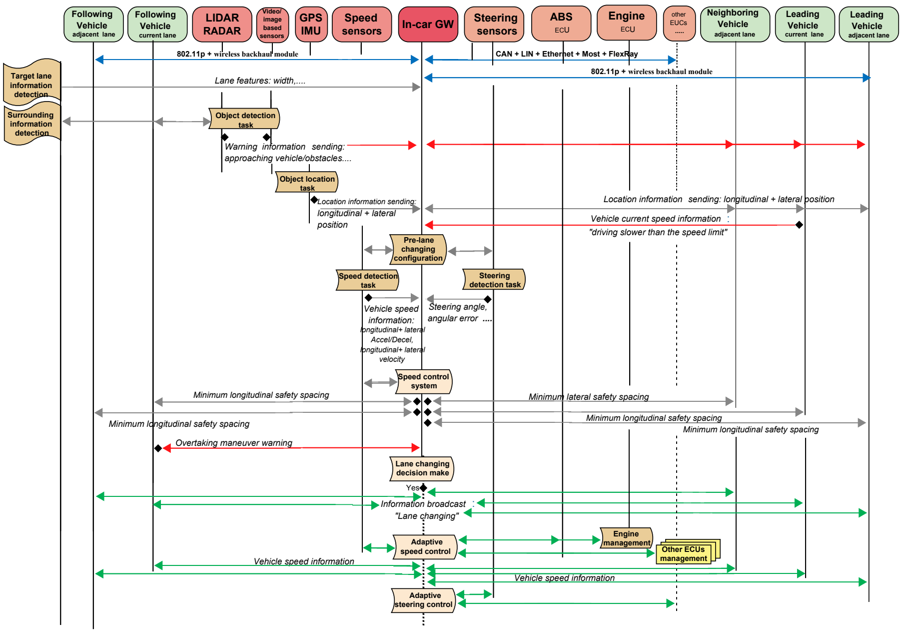

Fig. 12 Information flow during the lane changing decision

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Figures

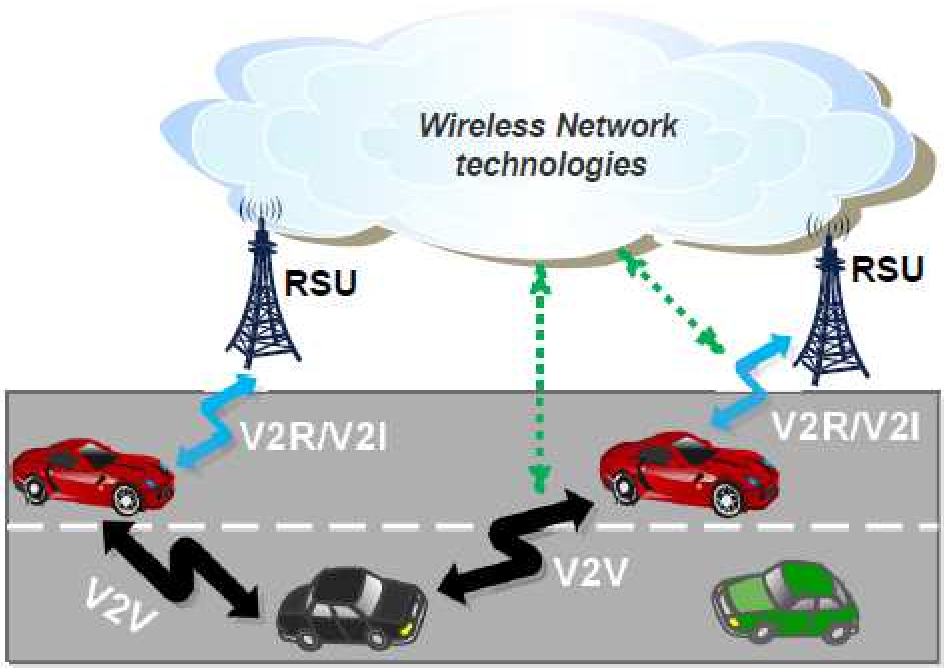

Figure 1

VANET main communication types

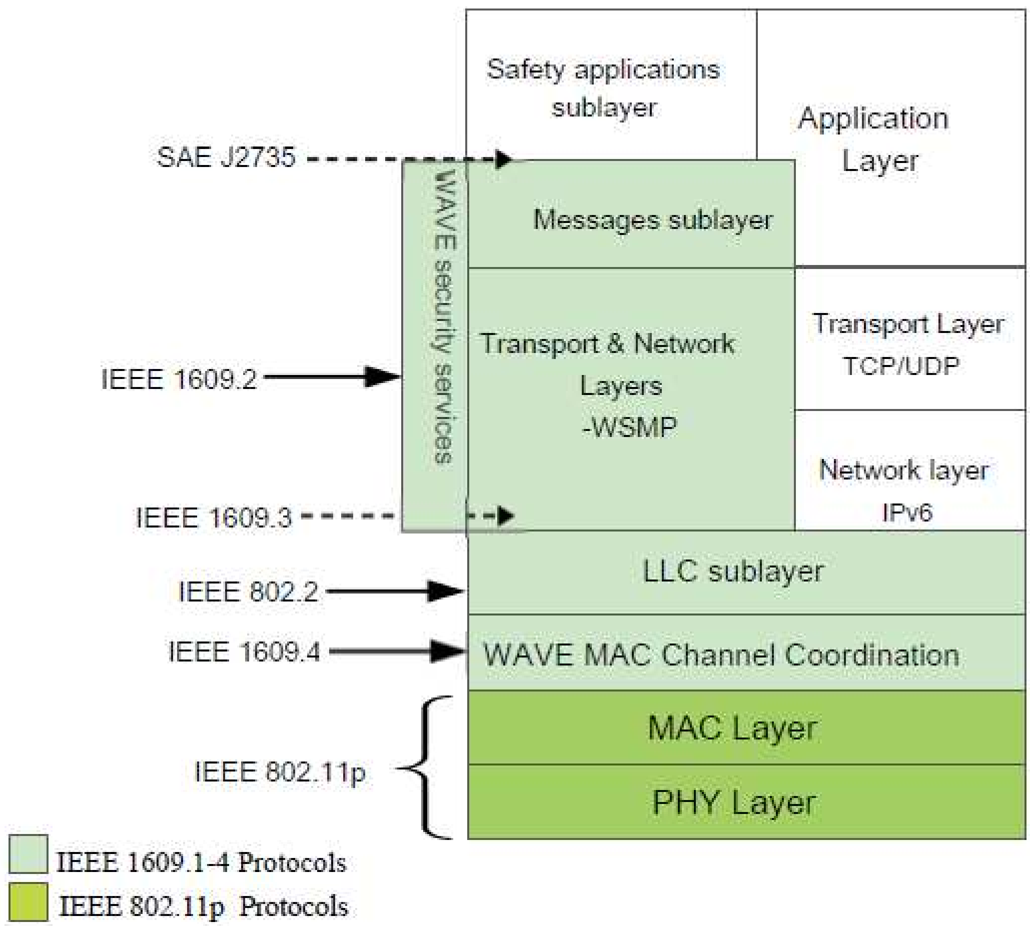

Figure 2

Protocol stack for WAVE standard

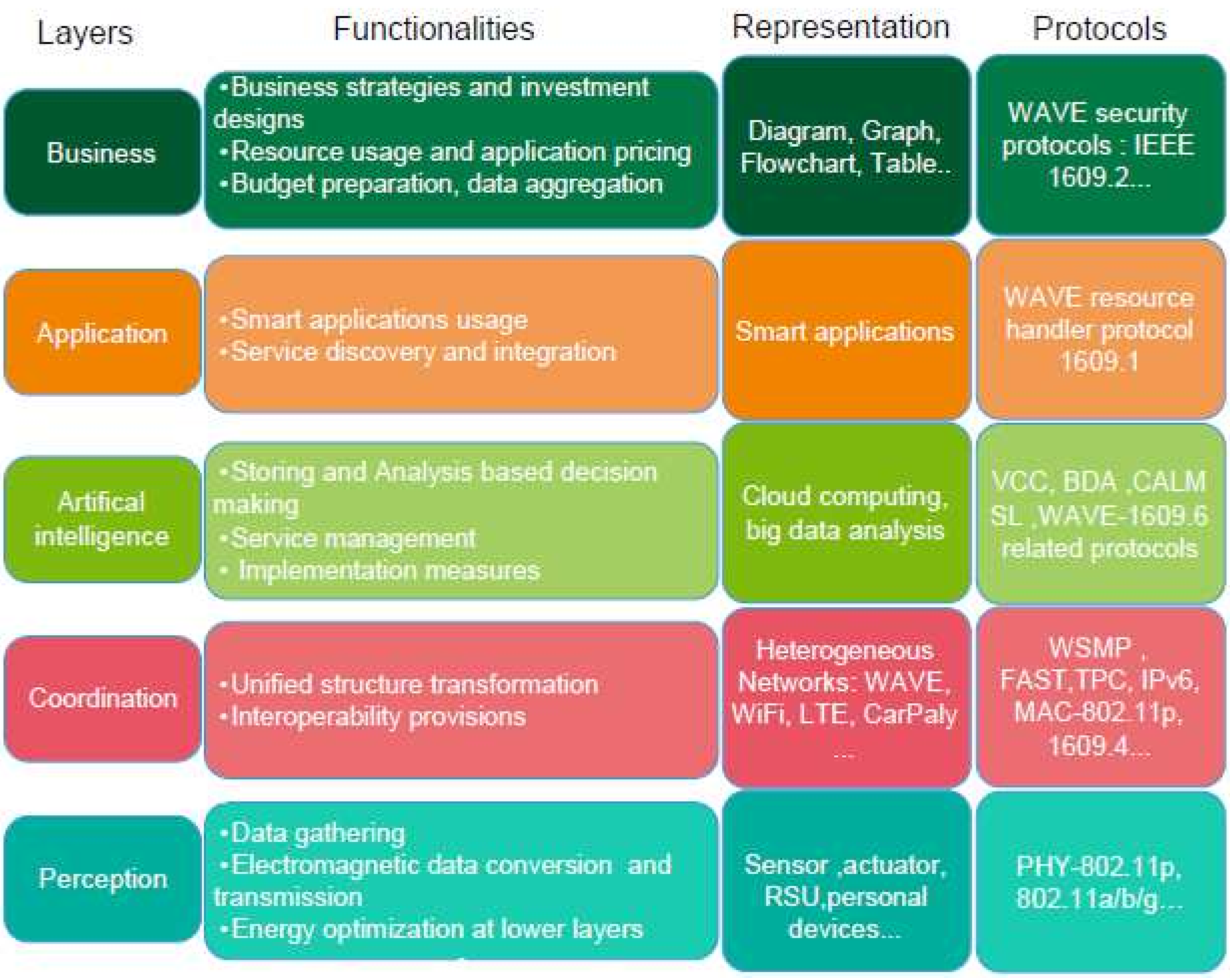

Figure 3

Layered IoV architecture and protocol stack

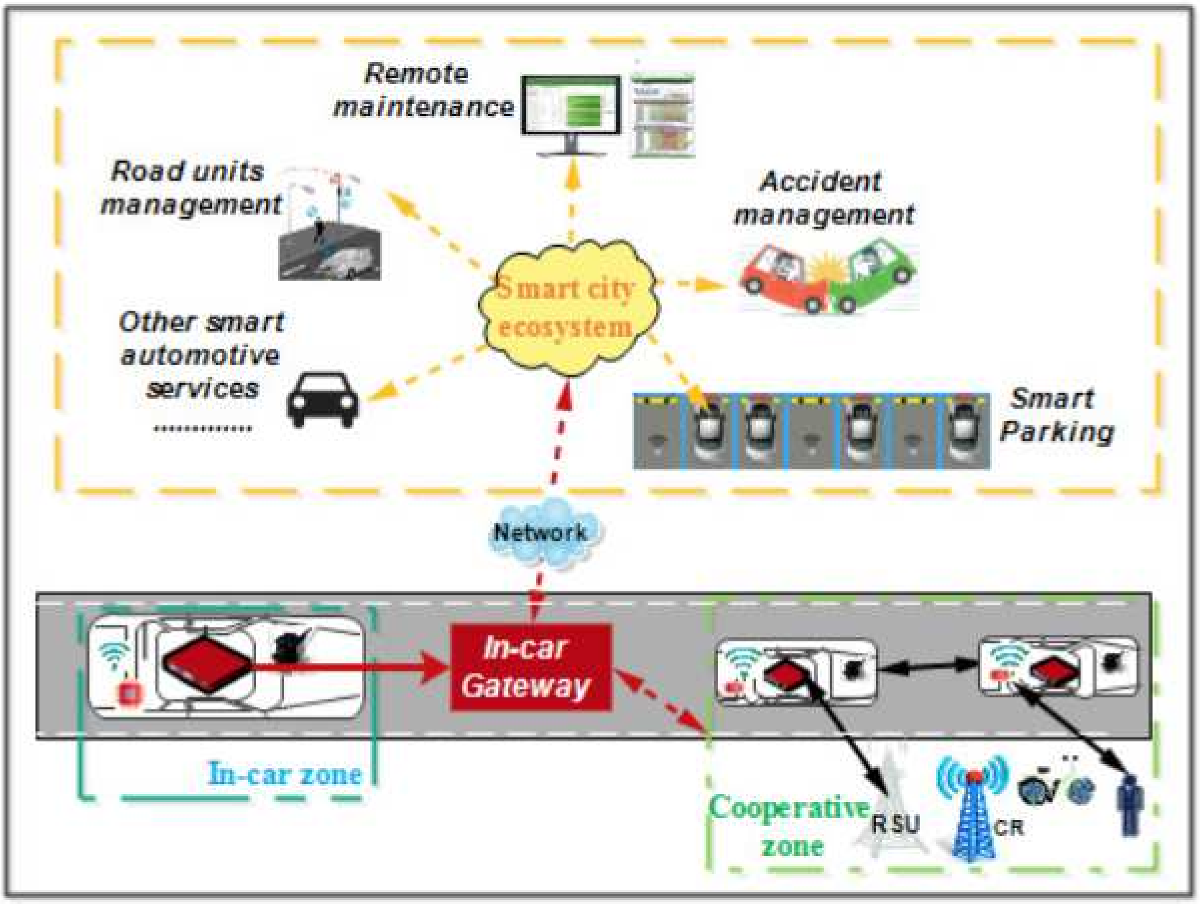

Figure 4

Communication system

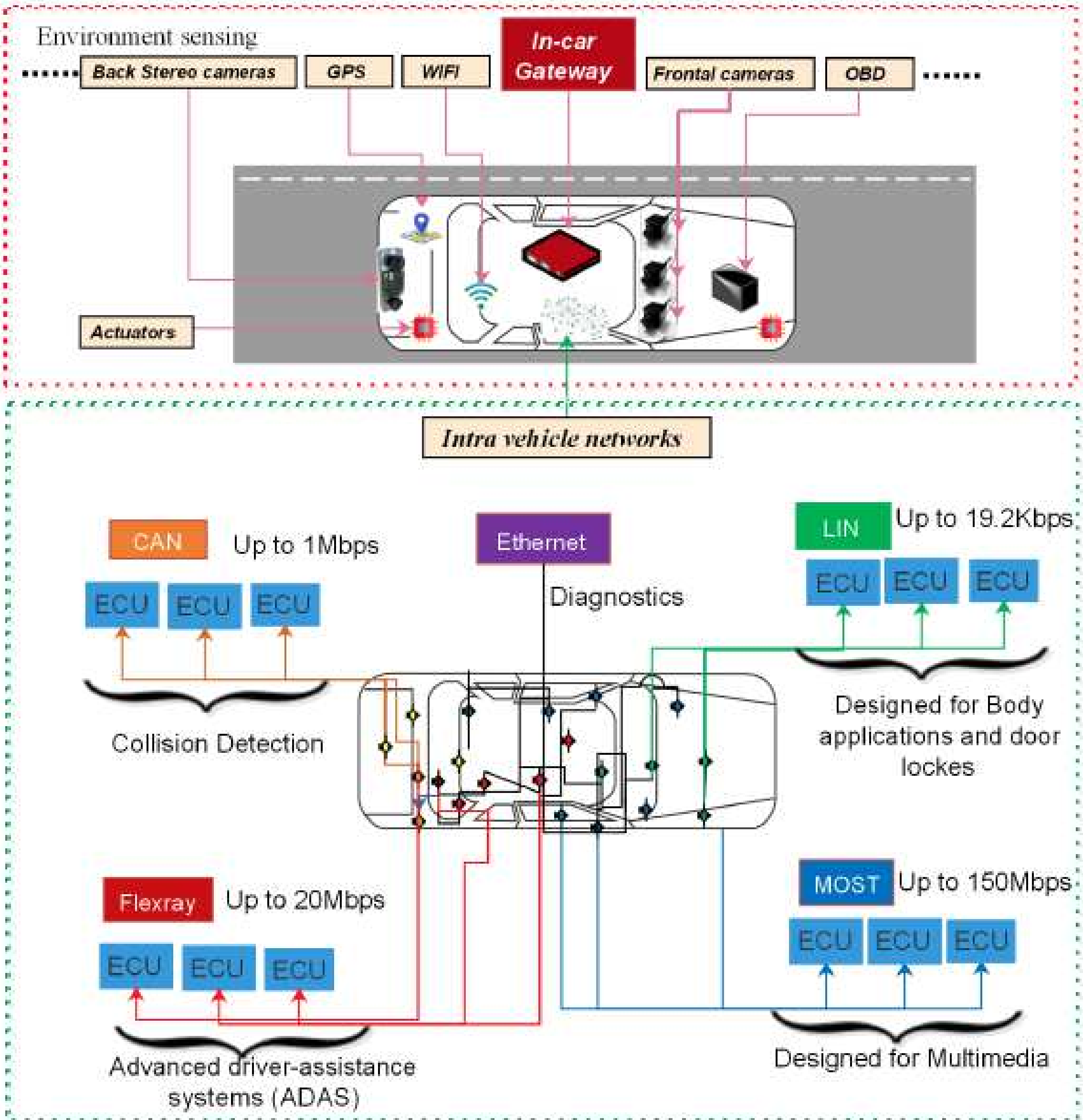

Figure 5

Car Zone

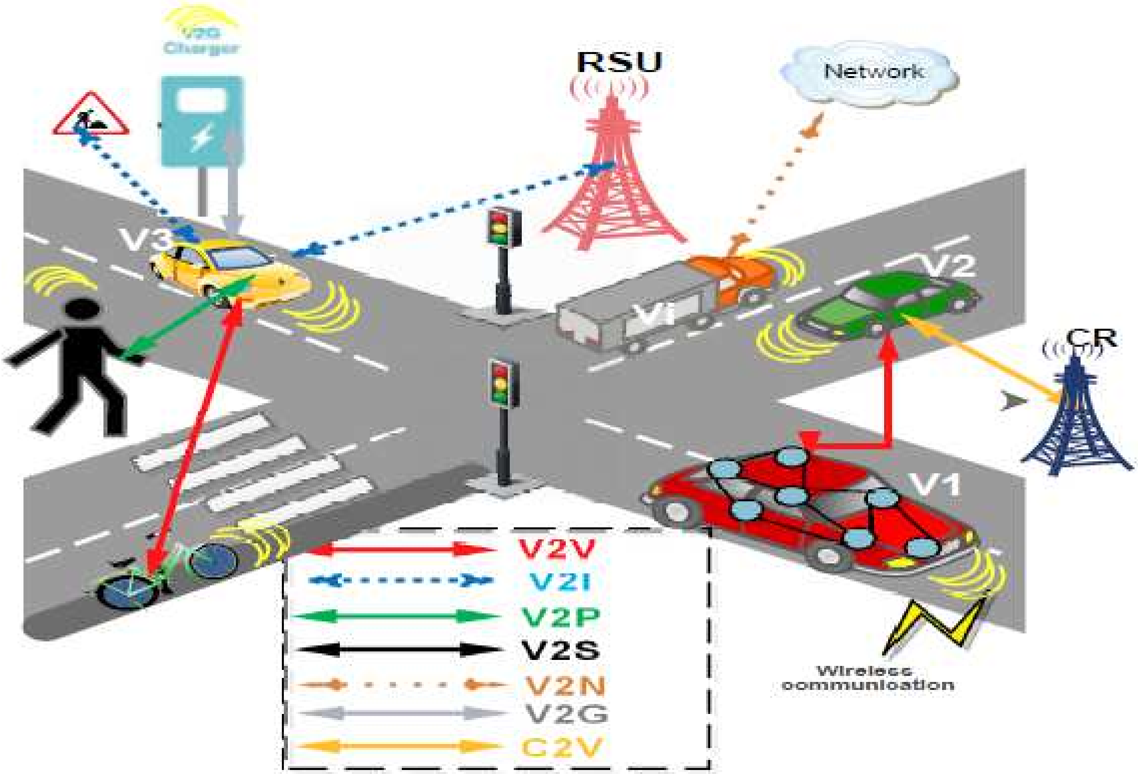

Figure 6

Cooperation zone: Vehicle communication types

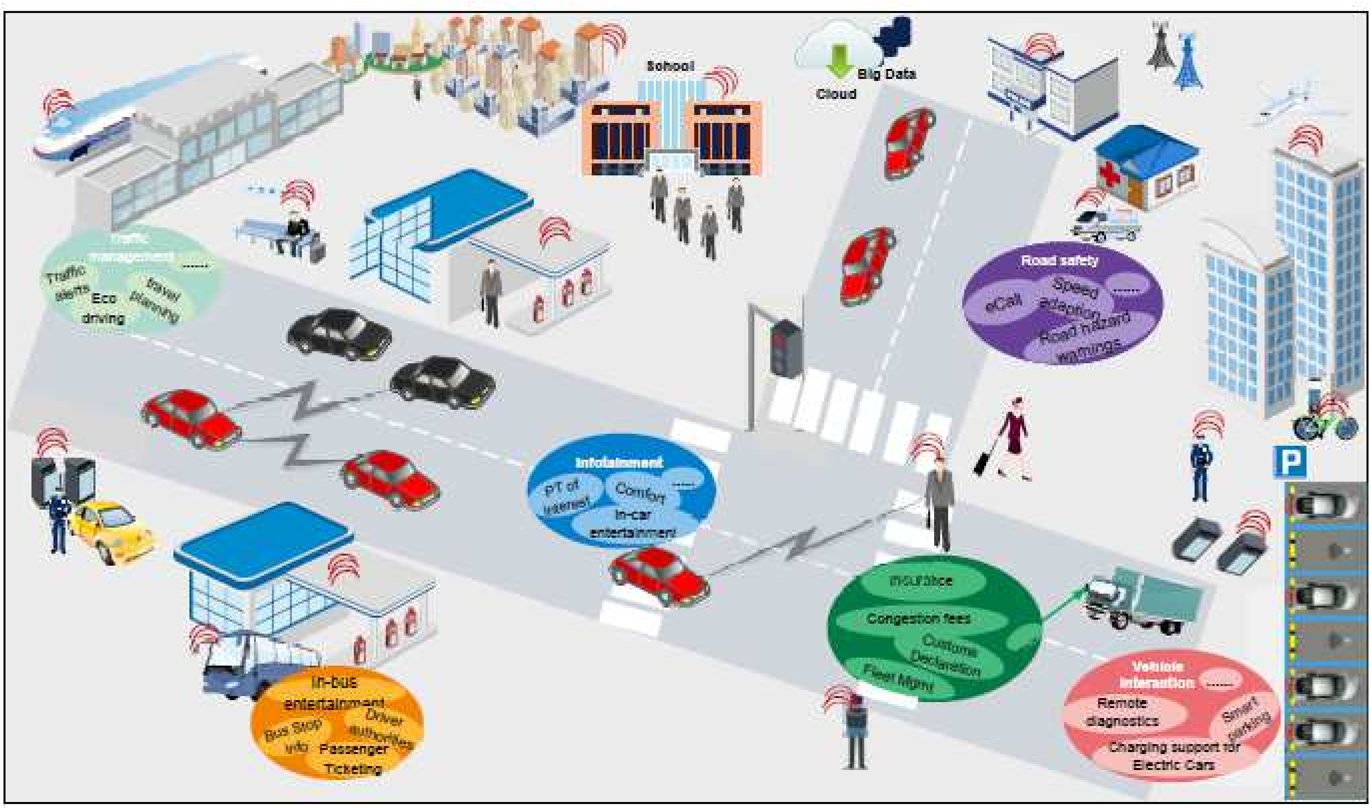

Figure 7

Smart city ecosystem

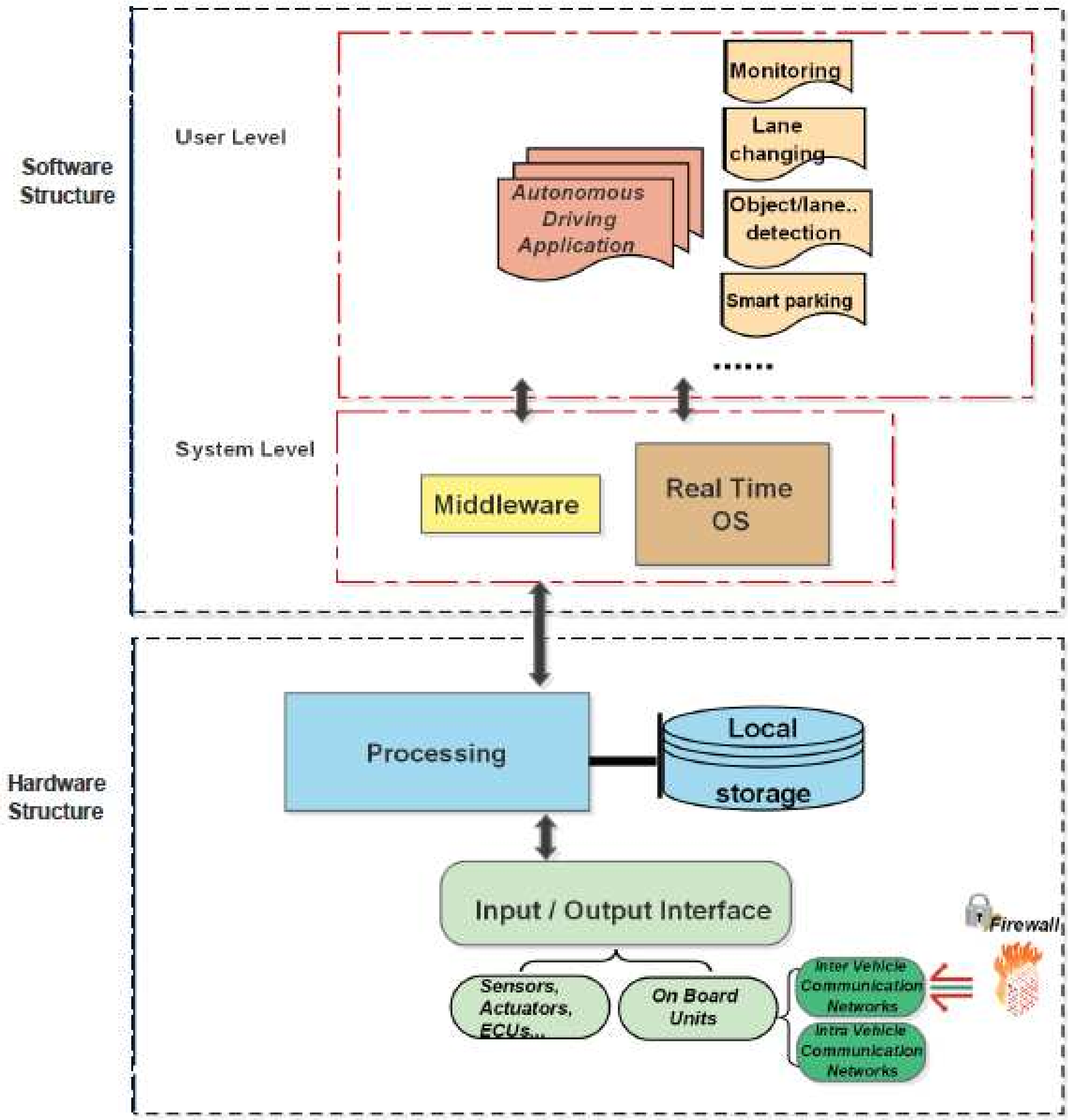

Figure 8

In-car gateway global architecture

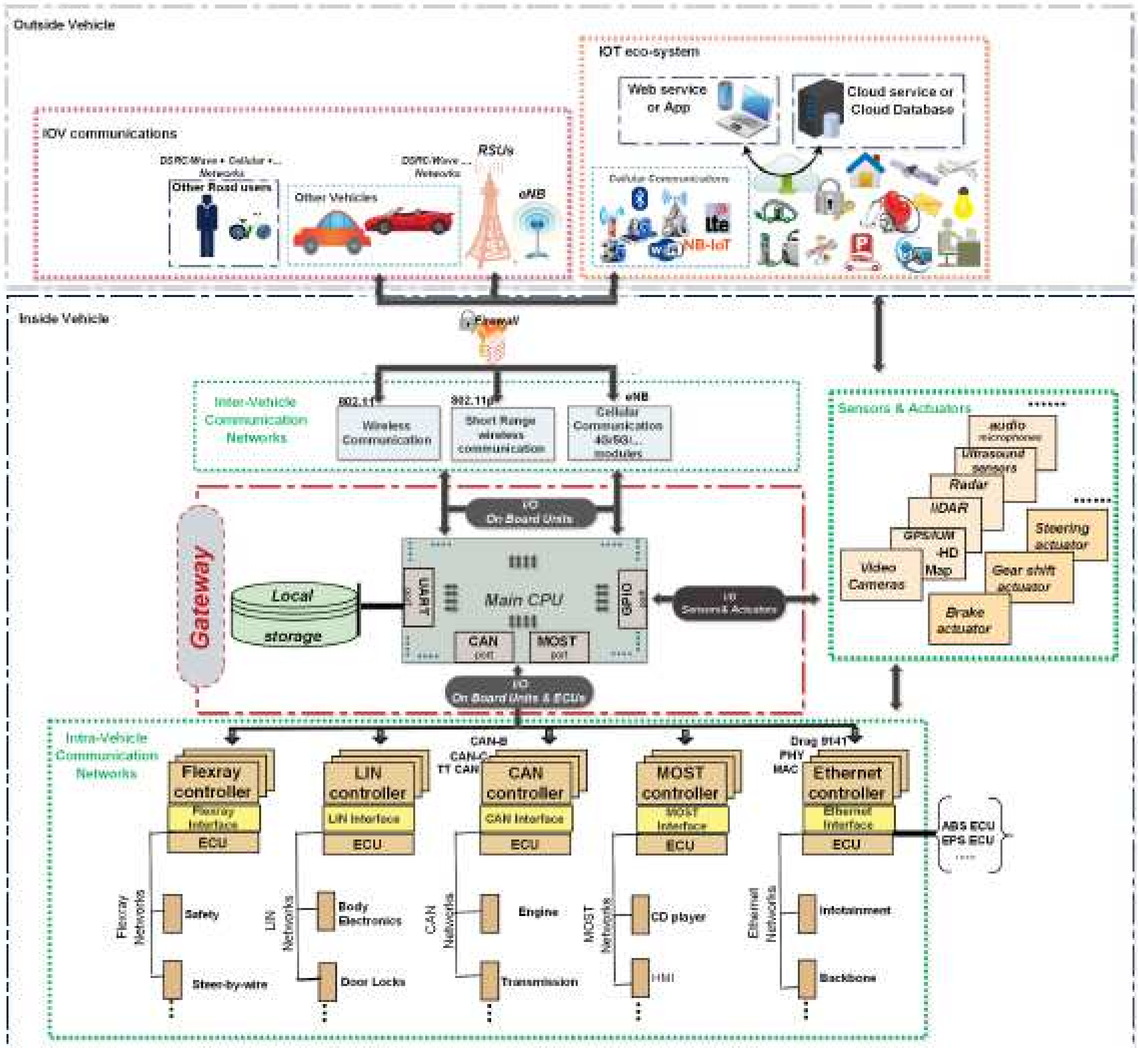

Figure 9

In-car gateway hardware architecture

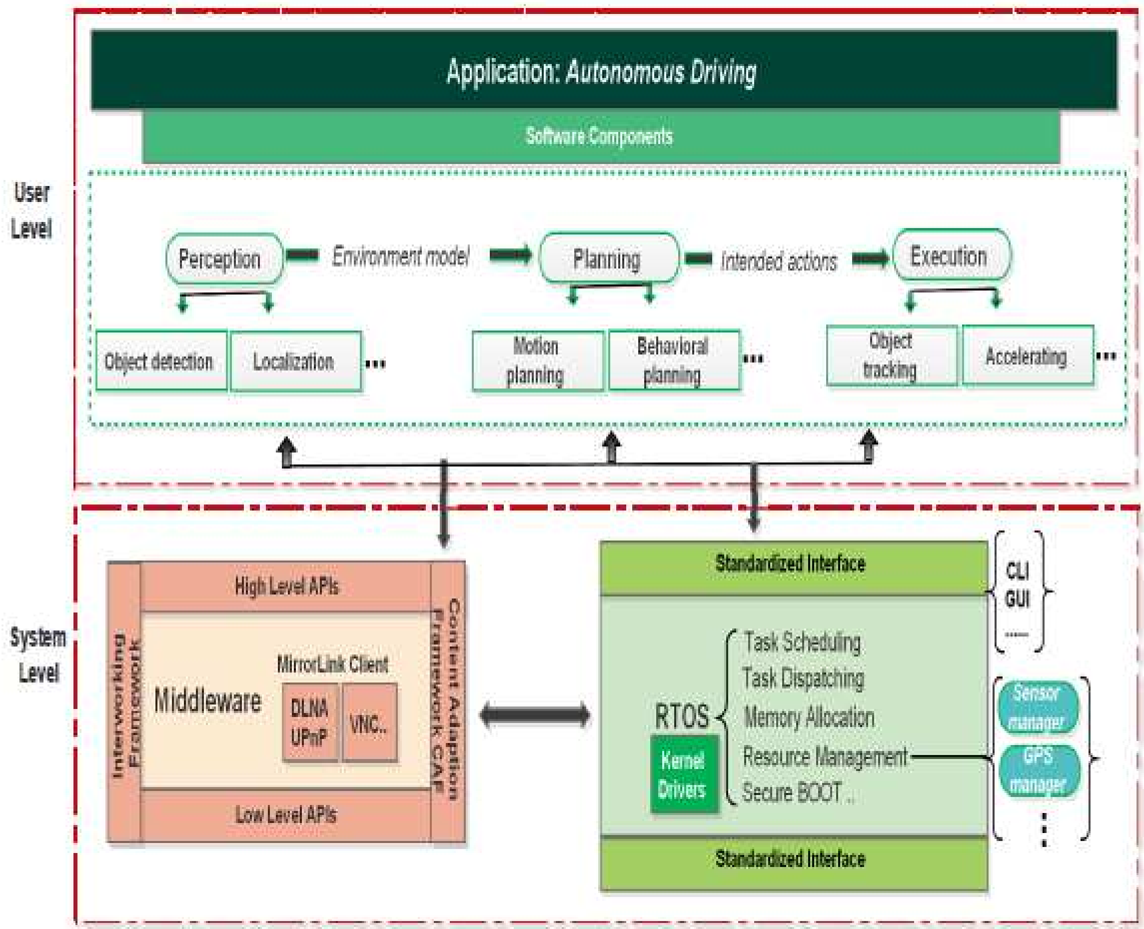

Figure 10

In-car gateway software architecture

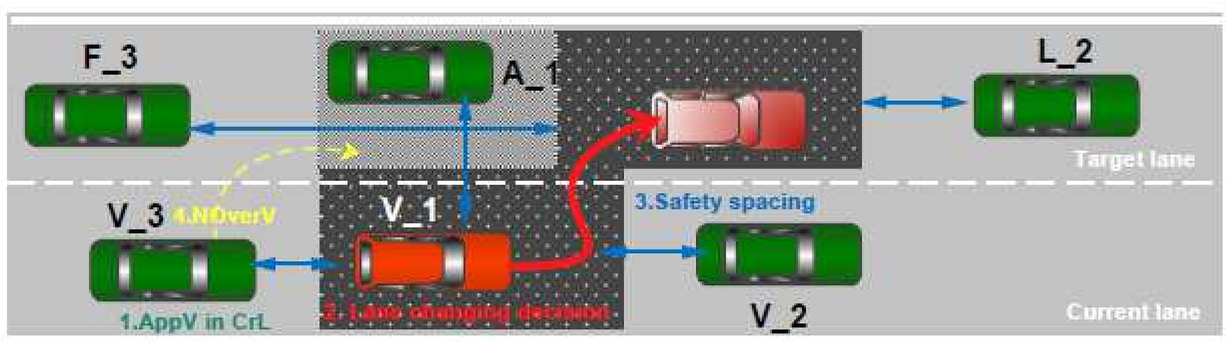

Figure 11

Lane changing scenario

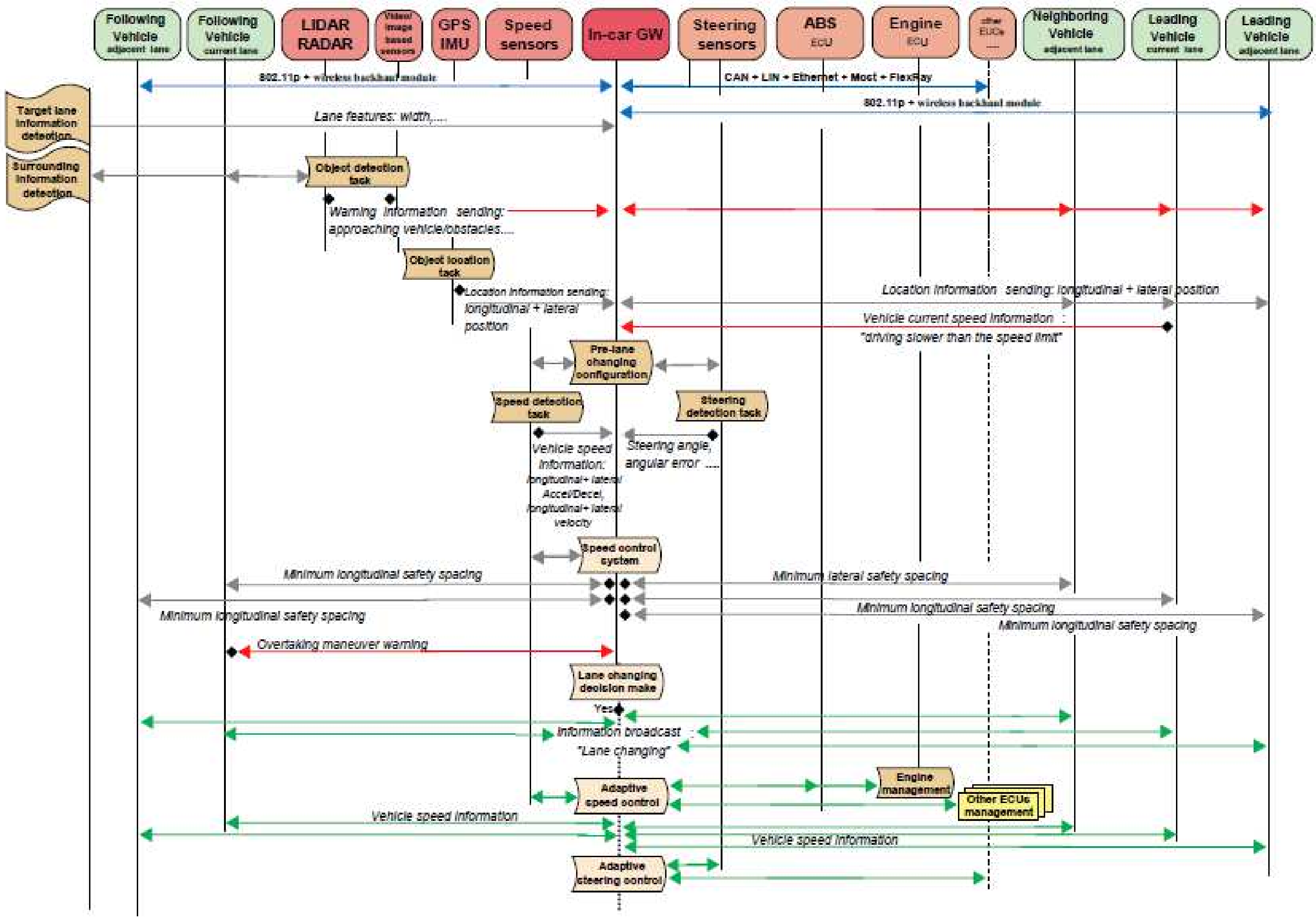

Figure 12

Information flow during the lane changing decision