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Article *in* Arabian Journal for Science and Engineering · May 2019

DOI: 10.1007/s13369-019-03870-2

Arabian Journal for Science and Engineering
https://doi.org/10.1007/s13369-019-03870-2

REVIEW - COMPUTER ENGINEERING AND COMPUTER SCIENCE

Toward an Efficient Deployment of Open Source Software in the Internet of Vehicles Field

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Received: 19 December 2018 / Accepted: 21 April 2019

Abstract
Recent developments in communication technologies, hardware and software are facilitating the implementation of different types of intelligent networks in various environments. One such network is the Internet-connected vehicles network. Internet of Vehicles (IoV) has recently become an active area of standardization, development and research, because it has shown to improve vehicle usage, traffic efficiency, road safety, as well as drivers' and passengers' comfort. As vehicles are becoming more connected and smarter, they are also becoming more reliant on software built with open source software (OSS). The deployment of OSS in the IoV field is, however, erratic and does not follow a clear approach. This study overviews the different applications in IoV as well as the existing and available open source software, in order to represent the current state of how this software paradigm is being used in IoV. This study also outlines challenges that remain to be addressed if we are to facilitate the widespread deployment and prevalent implementation of open source in IoV. Finally, this study explores some potential opportunities within IoV open source software for developing different IoV applications.

Keywords Open source software · Internet of Vehicles · Architecture · OSS · IoV

1 Introduction

In this era of significant advancements in automotive technology, the necessity for wireless communications among vehicles has become more apparent. Wireless data dissemination and delivery of data to/from the vehicles that constitute a vehicular network enable a wide variety of services for upholding safety and non-safety applications (the latter, also known as comfort or infotainment applications) [1]. An effective distribution of information in data packets form is indispensable to supporting the smart Intelligent Transportation Systems concept [2]. Safety applications include accident warning/avoidance, dynamic speed limits, traffic congestion reduction and cooperative driving. Ensuring drivers' safety and providing traffic information through wireless communications saves lives, prevents time and energy wastage and reduces pollution. Non-safety applications include Internet access, multimedia streaming, file sharing and highway services, to mention just a few [1].

Communication networks, formed by the ensemble of moving vehicles, are distinguished by the intrinsic properties of their vehicular environments, such as high-speed mobility, dynamic topologies, highly variable channel conditions and limited mobility due to road map limits. As a result, widely available protocols for non-vehicular wireless networks may not satisfy the varying requirements of vehicular applications or may prove to be inefficient in vehicular settings [1]. Hence, new communication protocols and software and simulation environments need to be developed according to specific requirements within vehicular networks and to ultimately be deployed [3].

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Journal: **13369** MS: **3870** TYPESET DISK LE CP Disp.:**2019/5/6** Pages: **23** Layout: **Large**

As the automotive industry becomes increasingly more software-driven, open source will eventually drive innovation faster and more reliably. Be it for navigation, music and media, or mobile phone support, connected vehicles are more likely to interface with features built on top of OSS. An open platform across the entire vehicles industry empowers suppliers and manufacturers to reuse and share the same code, reduces the cost of development, cuts the time-to-market for new products and helps to maintain the health of this industrial sector.

IoV applications software requires both strong, secure architecture and a guaranteed compatibility of the implemented software platform with the conventional and existing vehicular standards for safety, quality and cost. In an effort to achieve vehicular connectivity, alliances between companies have enabled them to collectively share the development costs and resources to produce what is called the "closed proprietary OS." However, one of the major concerns with closed proprietary software is its lack of flexibility in architectural design, since its products are more or less fixed by the supplier.

On the other hand, OSS is entirely provided in the desired form for flexible software changes, given its intellectual property clauses that permit use, modification and redistribution. Permissions issued under copyright law allow for efficient software developments and improvements to already-existing source code. The success of OSS is mainly due to copyright laws that protect the code and aid authors to limit authorizations according to the terms of the license.

Several openness goals may be achieved with open platforms, open interfaces and revealed source code details and hardware designs. The rising importance of personal and technical data produced by cars and within cars introduces an additional concern for openness, specifically regarding data. Connected cars must share data with other tools and software in order to exchange locations, maps, news and entertainment, traffic information and other forms of data. The self-driving car is conceived to exchange data with other participants in the network of traffic for safety purposes, including cyclists, other cars and pedestrians. Information exchange requires standardized and open communication protocols, in addition to open software.

The integration of OSS in Internet-connected vehicles will thus weaken the entrance barrier for several independent applications. This enables a large community of developers to analyze the interdependencies of onboard embedded software and thereby to gain full control over final implementation. If given this opportunity, an open connected car platform will set in motion an innovative evolution of services over the car's lifetime. The main contributions of this study are listed below:

- To investigate and give an overview of various applications that have been proposed so far for IoV;
- To provide a detailed list of OS and proprietary IoV software;
- To identify challenges facing the application of IoV;
- To delve into potential areas for the deployment of OSS in the IoV field.

The structure of the paper is as follows: Sect. 2 introduces the state-of-the-art of software deployment in IoV. Our methodology is described in Sect. 3, while Sects. 4 and 5 answer the research questions and provide a detailed and systematic review of the literature on IoV architecture and applications. Section 6 elaborates on open source software for IoV. Sections 7 and 8 discuss the challenges and benefits of adopting OSS in IoV. The areas where OSS can make a difference in the IoV field are detailed in Sect. 9. The conclusion is presented in the last section.

2 Related Work

Many research papers on IoV have been published in connection with wireless technology conferences and workshops, and in journals. In this section, the state-of-the-art of software deployment in IoV is presented.

In 2011, Martinez et al. published a paper [4] titled "A survey and comparative study of simulators for vehicular ad hoc networks (VANETs)" in *Wireless Communications and Mobile Computing*. The paper is a comprehensive study and comparison of several different connected vehicles simulation software. More specifically, the paper compares different software features, graphical user interfaces (GUIs), accessibility, output visualization and precision of simulation.

Another paper by Nimje et al., published in March 2013 [5], evaluates the results of intravehicular communication protocols. The study also provides a list of various mobility models and underscores the importance of bidirectional coupling for merging both road traffic simulation and a network simulation's environments for representational modeling.

Vehicular Cloud Computing (VCC) was also introduced as a novel hybrid technology that notably impacts traffic management and overall road safety. In a paper published by Md. Whaiduzzaman et al. [6], the state of the art of VCC was presented. The paper also provides a taxonomy of the vehicular cloud and its numerous applications, cloud formations, as well as several privacy and security issues.

It should be noted that all of the aforementioned papers on IoV software either investigate the integration of a set of IoV software without first considering whether they are open source or proprietary, or they study one specific category of IoV software without considering other categories and their live interactions in implemented vehicular applications. This

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Table 1 Systematic literature review summary

Q1: What are the software applications of IoV?			
IoV architecture		Categories of IoV applications	
Protocols at physical world layer (10) Protocols at gateway layer (22) Protocols at fog layer (29) Protocols and platforms at cloud layer (11) Protocols at application layer (3) User layer application requirements (30)		Autonomous (52) Navigation (53) Safety (121) Comfortable experience (48) Smart traffic lights (36) Smart parking (36) Advertisements and Commercial (6)	
Q2: What are the available IoV open source softwares?			
V2X	Simulation (37)	Services (6)	Cloud (5)
Q3: What are OSS development challenges for IoV?			
Scalability (45) Intelligence (44) Security and privacy (69) Connectivity and big data (83)		Performance (103) Reliability (49) Standardization (79)	
Q4: What are the opportunities of using OSS with IoV?			
Autonomous		Scalability	
Navigation		Intelligence	
Safety		Location accuracy	
Comfortable experience		Connectivity and big data	
Smart traffic lights		Performance	
Smart parking		Reliability	
Advertisements and commercial		Standardization	
A. Road safety applications 1. Post-crash notification (PCN) 2. Lane change assistance (LCA) B. Traffic management applications 1. Navigation: congestion road notification (CRN) 2. Smart vehicle parking C. Comfort and infotainment applications 1. Energy optimization and emission reduction 2. Comfortable passenger experience			

(*) indicates number of papers

has inspired the authors of the present paper to expand upon these studies and to put forward a study in which an ample set of IoV applications are presented, as well as to discuss the available state-of-the-art open source IoV software. The aim is to encourage researchers in the field to adopt OSS by assisting them with helpful insights on applications, challenges and potential prospects for IoV. Table 1 summarizes the findings of a systematic review of the literature.

3 Methodology

More than 200 research papers and articles were collected from various sources, as in the last 10 years, a growing number of organizations have shown interest in OSS and in how to implement it in IoV devices. The steps listed in Fig. 1 outline the search and selection process for the research papers used in this study. After weeding out duplicate papers found within the initial collection, as well as unrelated papers, a total of 157 papers remained.

3.1 Literature Resources for the Study

The relevant articles were found in the following digital libraries:

- IEEE Xplore
- ACM digital Library
- Researchgate
- Other sources
  - Educause
  - Springer
  - Dwheeler

During this study, 216 papers were considered (157 of them formed the basis of this study due to their relevance to

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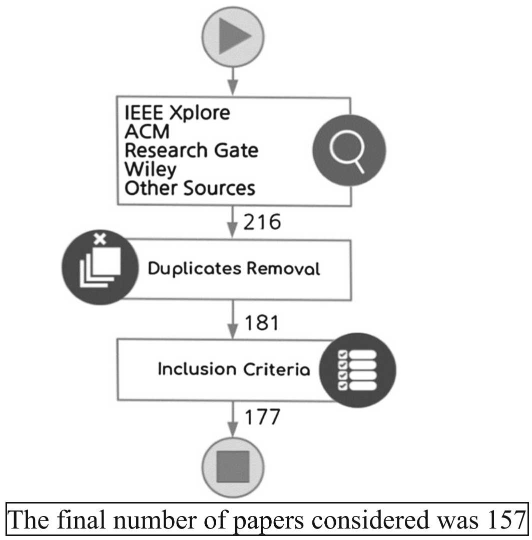

Fig. 1 Selection methodology

this research) in order to tackle the research questions below, detailed in Fig. 2.

4 IoV Architecture

Many papers [7–11] have sought to propose a model of IoV architecture. Kaiwartya et al. [10] have proposed a five-layered architecture, shown in Fig. 3. The layers are from top to bottom: business, applications, artificial intelligence, coordination and perception. The perception layer consists of sensors, vehicle actuators and a roadside unit (RSU) that supports passing vehicles' connectivity and personal devices. The coordination layer secures the transmission of information that the cloud infrastructure has to process. The artificial intelligence layer ensures big data analysis, expert systems functions and cloud computing, in order to make informed decisions regarding the best applications for intelligent services, traffic safety, infotainment and multimedia. End users' intelligent and smart services, application usage data and statistics and service discovery and integration are all functionalities of the application layer. The business layer uses statistical analysis to draw flowcharts, graphs, diagrams and tables to provide a business model. As indicated in Fig. 3, Kaiwartya et al. [10] proposed an architecture that recognizes and clusters together similar functionalities and different elements of varied networks in the form of layers. Its number of layers is optimized and enhances the distinction between layers. Additionally, it is open to technological adaptations that allow for more OSS deployment.

Talal et al. provided the details of protocols, technology and applications for each layer of IoV, as indicated in Tables 2, 3, 4, 5, 6 and 7.

The present research adopts this thorough description in the context of IoV architecture and OSS deployment and has garnered the following observations:

1. At layer 1, the OSS community might consider developing and deploying solutions for common industrial protocol (CIP) and I2C protocols.
2. To cover all protocols for layer 2, OSS solutions are recommended for the WME protocol. Additionally, Table 3 indicates that there is erratic deployment of OSS solutions for QoS and Communication protocol types.
3. At layer 3, the OSS community might consider developing and deploying solutions for WiMax and LPWAN protocols. Additionally, Table 4 indicates that there is erratic deployment of OSS solutions for TCP, STCP and UDP protocols.
4. At layer 4, the OSS community might consider developing and deploying solutions for the Infrastructure as a Service and Service-Oriented Architectures categories.

5 Applications of IoV

Vehicular applications are numerous compared to protocol solutions that are deployed in the context of IoV. They are generally categorized as (i) applications for road safety (ii) applications for traffic management [67] and (iii) applications for infotainment. The first type aims to reduce the risk of car accidents and ensure a safe driving experience by providing information about potential dangers and obstacles. The essential idea is to extend the driver's field of perception, enabling them to react more quickly to wireless communication alerts [2]. The second class of applications focuses on effective management of the flow of traffic in view of preventing traffic jams and optimizing travel time. These applications, which may include lane-merging assistance, optimal scheduling of traffic lights and enhanced guidance/navigation, aim to optimize routes and reduce fuel

Q1: What are the software applications of IoV? →Q2: What are the available IoV open source software platforms? →Q3: What are the OSS development challenges for IoV? →Q4: What opportunities exist for using OSS for IoV?

Fig. 2 Research questions

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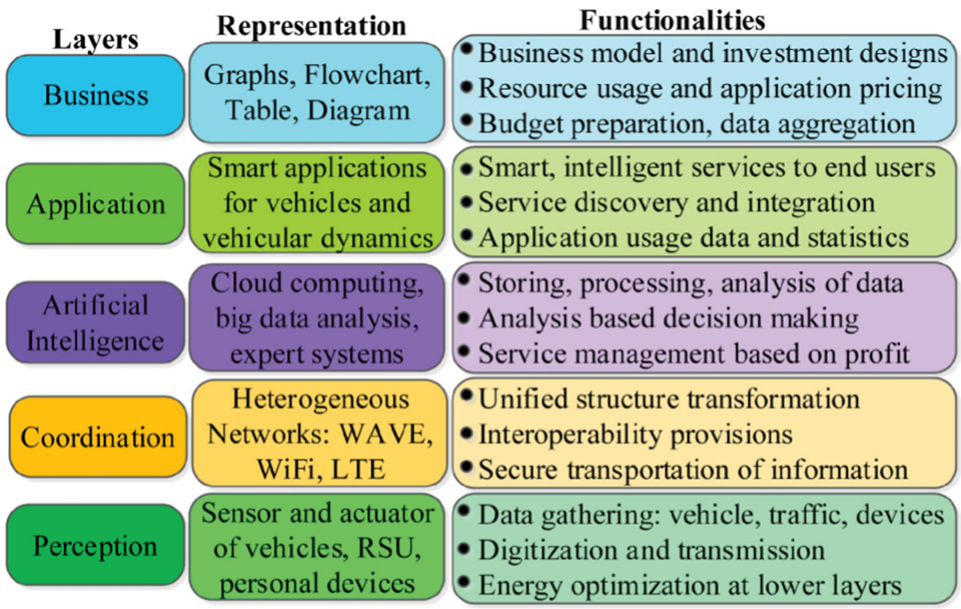

Fig. 3 IoV-layered architecture

Table 2 Protocols at physical world layer

Protocols	Communication	Type	Description	List of OSS
PMD	Intravehicle	Interface protocol	Helps wireless devices to interface with each other in the same vehicle	NS2 [4, 5, 12–17]
PLCP	Intravehicle	Mapping protocol	Assists as a mediation layer between an ODM unit and MAC frame for several units of physical layer communication	NS2 [4, 5, 12–17]
PLME	Intravehicle	Connection protocol	Aids in forming a WAVE connection of compliance media for communication between vehicles	NS2 [4, 5, 12–17]
CAN	Intravehicle/V2S	Communication protocol	Supports communication among onboard units and vehicle sensors	Automotive Grade Linux (AGL) [18]
RTP	Intra vehicle	Communication protocol	Assists in the delivery of Audio and Video content over IP within vehicle	NS2 [4, 5, 12–16], GlomoSim [4, 13, 14, 17, 19]
RTSP	Intra vehicle	Streaming/communication protocol	Contributes to monitoring servers for streaming different media inside the vehicle	NS2 [4, 5, 12–17]
CIP	Intra vehicle/V2S	Control and information protocol	Helps to collect information from different vehicle sensors for automation manufacturing	No OSS is found
I2C	V2S	Intraboard communication	Supports the interface of different vehicle modules with the onboard unit	No OSS is found

consumption and emissions. While the essential goal of connected vehicles is to promote safety and non-safety applications, vehicle connectivity is also expected to generate profitable opportunities in substantially equipping vehicles with onboard wireless media. Infotainment applications focus on providing the traveler by road with entertainment and information to make the ride more enjoyable. In this section, we describe the key features of entertainment and safety applications for connected vehicles. Our findings are as follows:

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Table 3 Protocols at gateway layer

Protocols	Communication	Protocol type	Description	List of OSS
MAC	V2V/V2I	QoS	Contributes to preventing and resolving packet collisions in multilane contexts	SUMO [4, 5, 13, 14, 20–31] NS2 [4, 5, 12–17] GlomoSim [4, 13, 14, 17]
LLC	V2V/V2I	Connection	Contributes to forming connection-oriented and connectionless services among the infrastructures and vehicles	NS2 [4, 5, 12–17]
WME	V2V/V2I	Processing	Helps in the execution of frame queuing processing and management, channel prioritization and safety messages handling	No OSS is found
WSMP	V2V/V2I	Transmission	Supports safety information exchange and packets transmission at data rate or low power	VEINS [5, 14, 21, 24, 27, 30–33]
TCP/IP	V2V/V2I/V2P	Communication	Assists in communicating with the Internet or local network	SUMO [4, 5, 13, 14, 20–31] NS2 [4, 5, 12–17] GlomoSim [4, 13, 14, 17]

Table 4 Protocols at fog layer

Category	Protocols	Description	List of OSS
Communication	Wi-Fi	High bandwidth, low range	VANETsim [34] Automotive Grade Linux (AGL) [18]
	WiMax	High bandwidth, energy cost and wide range	No OSS is found
	DSRC	Communications for dedicated short range	NS2 [4, 5, 12–17] VEINS [5, 14, 21, 24, 27, 30–33] GrooveSim [35]
	LPWAN: SigFox, LoRa	High bandwidth, energy efficient	No OSS is found
	Cellular (LTE-A)	High bandwidth and wide range	VEINS [5, 14, 21, 24, 27, 30–33], mangOH [36]
IP	6LoWPAN	Compressed IPv6 for low-power devices	OMNET++ [5, 13, 14, 16, 17, 20–22, 25–29, 31, 37–39] CarGeo6 [40]
Transport	TCP	Single-stream transmission	OMNET++ [5, 13, 14, 16, 17, 20–22, 25–29, 31, 37–39] NS2 [4, 5, 12–17] GlomoSim [4, 13, 14, 17, 19] CarGeo6 [40] GrooveSim [35]
	SCTP	Multi-tenant streaming	OMNET++ [5, 13, 14, 16, 17, 20–22, 25–29, 31, 37–39] CarGeo6 [40] NS2 [4, 5, 12–17] GlomoSim [4, 13, 14, 17, 19]
	UDP	Individual datagram communication	OMNET++ [5, 13, 14, 16, 17, 20–22, 25–29, 31, 37–39] NS2 [4, 5, 12–17] GlomoSim [4, 13, 14, 17], GrooveSim [35]

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Table 5 Protocols and platforms at cloud layer

Technology	Category	Protocols and platforms	List of OSS
Virtualization	S (Sensing) aaS	OpenIoT	Autoware [41, 42]
	IaaS	CloudStack, OpenStack, OpenNebula	No OSS is found
	S (Storage) aaS	Amazon S3	Trafficdb [43] mangOH [44]
	NaaS	Network Function Virtualization (NFV), Software Defined Networking (SDN)	TinyOS [45]
	PaaS	Google AppEngine, Amazon EC2	PNDA [46] Legato [47]
Web services	SOA (service-oriented architecture)	Web Services Description Language (WSDL), Simple Object Access Protocol (SOAP), Discovery, and Integration (UDDI), Universal Description,	No OSS is found
	REST (representational state transfer)	HTTP, COAP	Californium (Cf) CoAP Framework [48]
Data analytics	Distributed storage	Apache HBase, Apache Hadoop HDFS	Ethereum [49] mangOH [44]
	Batch process	Apache Spark, Apache MapReduce	CarStream [50]
	Stream process	Apache Spark Streaming, Apache Storm	CarStream [50]

Table 6 Protocols at application layer

Protocols	Description	Transport	Security	List of OSS
HTTP	The underlying standard protocol to enable (Representational State Transfer) RESTFUL Services	TCP	HTTPS	Automotive Grade Linux (AGL) [18] Californium (Cf) CoAP Framework [48]
CoAP (constrained application protocol)	A specialized Web transfer protocol. It was created as an alternative to HTTP for constrained nodes and networks	UDP	DTLS	Californium (Cf) CoAP Framework [48]
MQTT (message queue telemetry transport)	An M2M or IoT connectivity protocol. It is designed to be a lightweight publish/subscribe protocol	TCP	TLS/SSL	Eclipse Mosquito [51]

5.1 Autonomy: 52 papers have addressed the concept of Autonomy in the context of IoV

IoV will contribute to the infrastructure of autonomous vehicles, enhancing their communication capabilities to provide the best automation experience.

A smart vehicle that employs technologies solely based on sensors can be converted to a completely self-driving vehicle. By contrast, a smart vehicle that depends on connectivity technologies cannot be completely converted to a driverless vehicle. This is because an automated or smart vehicle that depends on connectivity technologies will constantly request help from other vehicles and from the surrounding infrastructure to obtain needed information. Instead, autonomy can better be achieved through so-called converged car technologies, which are combinations, of sorts, of connectivity technologies and sensor-based technologies, thereby improving the overall performance of automated vehicles and equipping them with innovative solutions to overcome the potential limitations of each technology.

Figure 4 shows the three levels of car autonomy that can result from adopting either sensor-based technology, connected vehicle technology, or a combination of both.

Table 8 lists papers that target vehicle autonomy as an application of IoV.

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Table 7 User layer application requirements

Users at Layer	Applications	List of OSS
Physical-world layer: driver, passengers	Vehicle safety	Automotive Grade Linux (AGL) [18]
	Driver health monitoring	DrowTion [52]
	In-car infotainment	Automotive Grade Linux (AGL) [18] MirrorLink [53]
	Multi-passenger gaming	No OSS is found
Gateway layer: drivers, passengers	Roadworks warning	GENIVI [54]
	Traffic congestion	Waze [55]
	Live traffic conditions	Waze [55]
	Platooning	Plexe [56]
	Point-of-interest notifications	GENIVI [54] OsmAnd [57]
	Vacant parking information	Waze [55] Parkncloud [58]
	Nearby driver collaboration (Verse)	Verse Waze [55]
Fog layer: drivers, smart cities users	Traffic light management	SUMO [4, 5, 13, 14, 20–31]
	Vehicle tracking	OpenXC [59]
	Driver chat (RoadSpeak)	Waze [55] Telemap Gypsii
	Road safety messages (ICNow, SBone)	SBone [57] ICNow
	Warnings about accidents within a specific area	MITSIMLAB [60]
	Warning for emergency vehicle	MITSIMLAB [60]
	Advertisement commercial	
	Toll collection	Smart Highway Toll Collection System [61]
	Alternative routes (drive and share)	Drive and Share
Cloud layer: smart cities users	Traffic management	MITSIMLAB [60]
	Toll collection updates	Smart Highway Toll Collection System [61]
	Driver behavior (SocialDrive)	DYNAMIT [62]
	Update of maps (MobiliNet, Waze)	Telemap
	Highway information (GasBuddy, Moovit)	Moovit [63] GasBuddy [64]
	Weather information	Pikalert [65]
	Multimedia file sharing	Tizen [66]

5.2 Navigation: 53 papers have addressed the concept of Navigation in the context of IoV

Onboard navigation platforms rely on data analytics to offer both real-time traffic estimations and future predictions.

1. Real-time traffic estimation: This can be achieved by using moving vehicles or onboard smartphones for data sensing and uploading the data reports (including times, locations and directions of vehicles) to a central database. Real-time traffic conditions of the roads, such as the average running speed and traffic density, can be obtained through analysis of the collected data.
2. Remote vehicle diagnostics and road condition warnings: Utilizing the data collected from vehicles, drivers can obtain a better service interval based on their own driving habits and taking predicted wear and tear into account, instead of the traditional approach based on the number of kilometers travelled. More critically, important information regarding potential vehicle or road risks can be exchanged in real time. For instance, if a number of vehicles in the same area have their traction control systems turned on at the same time, the vehicles in this area will receive a warning about icy conditions, for instance, or fuel-efficient driving in heavy traffic, and so forth.

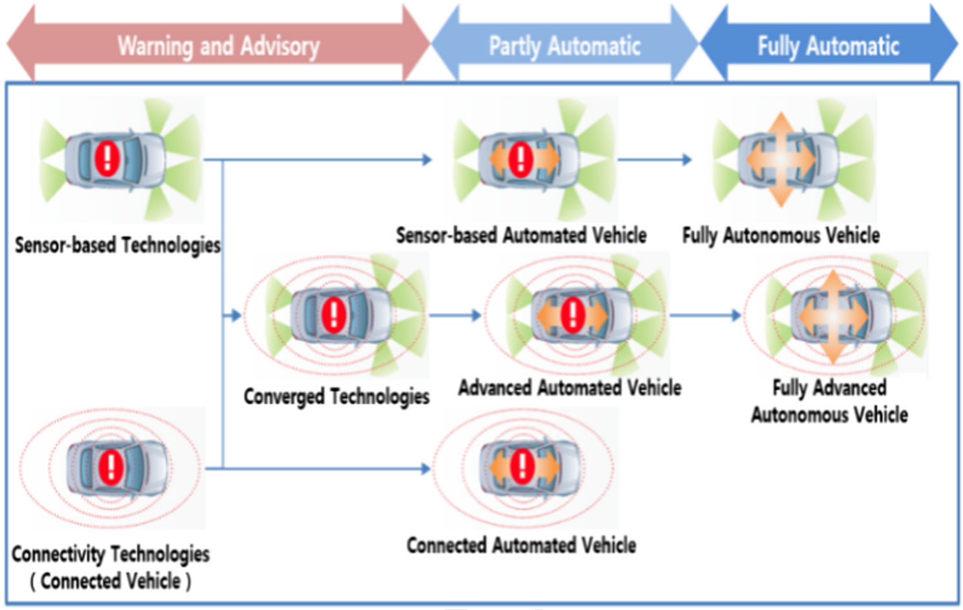

Fig. 4 Levels of car autonomy

Table 8 List of papers related to different categories of IoV applications

Category of IoV application	Description	Reference to papers
Autonomous	Gives cars the capacity to communicate with one another and with off-road infrastructures, to provide the best automation experience	[6, 13, 15, 17, 20, 22, 24, 30, 31, 33, 35, 41, 45, 50, 54, 57, 62, 65, 66, 69, 70, 73–85, 87–104, 131]
Navigation	Helps the user to find locations and share the location of vehicles. This information is then used by another navigation platform to indicate whether the roads are congested	[2, 3, 5, 6, 14–16, 22, 24, 26, 30–32, 35, 39, 41, 49, 54, 57, 64, 67, 73, 75, 76, 82, 85, 88–91, 95, 98, 99, 100, 102–120, 131]
Safety	Includes speed control and collision avoidance, in addition to anti-theft mechanisms and home-monitoring systems to track the car's location from home	[1–6, 12–22, 24–26, 28, 31–35, 38–41, 43–45, 49, 50, 53–55, 57, 58, 60, 62, 64–70, 72, 73, 75–77, 78–85, 87–99, 101, 103, 107–112, 114–116, 119–131, 133–150]
	Supplies the driver with Web access and audio and video streaming	[2, 3, 6, 12, 13, 15, 16, 21, 22, 24–26, 30, 33, 35, 38, 41, 43, 49, 54, 64–67, 69, 72, 73, 76, 81, 83, 85, 87, 91, 93, 98, 101, 103–105, 109–112, 114, 115, 117, 139, 151]
Comfortable experience Smart parking	Assists the driver in finding vacant parking spaces in specific regions	[2, 3, 6, 12, 13, 16, 18, 24–26, 30, 31, 35, 39, 41, 45, 64, 73, 75, 83, 88, 89, 92, 96, 100, 103–105, 107, 115, 125, 126, 135, 147, 152]
Advertisements and commercials	Service providers draw customers to their stores by announcing their services to drivers within communication range	[79–81]
Smart traffic lights	Traffic lights can be controlled to prioritize certain lanes when other lanes are empty; also when a traffic jam occurs, the service lane can be used as an extra lane	[4, 5, 13–15, 17, 20, 24–31, 83, 98, 109]

3. Fuel up or charge: While traveling in the city, electric vehicles/hybrid electric vehicles (EVs/HEVs) may decide at what time and location the car needs to fuel up or recharge at location-specific charging piles, by predicting the driving mileage based on real-time traffic conditions. The information provided by a connected vehicular transportation system is an important component for designing efficient means of resource management according to a smart grid system of the city.

Table 8 lists papers that target vehicle navigation as an application of IoV.

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5.3 Safety: 121 papers have addressed the concept of Safety in the context of IoV

Safety applications concern the surrounding road, nearby vehicles, road surface, bends in the road, etc. Road safety applications can be categorized as follows:

1. Real-time traffic: Real-time traffic information may be stored in an RSU and made accessible to vehicles whenever and wherever needed. This stands to contribute to solving traffic problems such as traffic jams, to avoiding congestion and to mitigating the site of emergencies and accidents though alerts, etc.
2. Cooperative Message Transfer: Slow/stopped vehicles may share messages and cooperate to assist other vehicles. Although reliability and latency are a primary concern in this regard, the application could potentially automate such things as emergency braking to avoid probable accidents. In the same manner, an emergency electronic brake light could constitute another application.
3. Road Hazard Control Notification: Cars communicating with other cars regarding landslides or data on road conditions, notifications on upcoming bends or sudden downhills in the road, etc.
4. Cooperative Collision Warning: Notifies two drivers who may potentially collide so they can change their course or act in consequence.
5. Traffic Vigilance: Cameras may be mounted on the RSU as an input and serve as the latest tool in low- or zero-tolerance campaigns against driving offenses.

Table 8 lists papers that target vehicle safety as an application of IoV.

5.4 Comfortable Experience: 48 papers have addressed the concept of a Comfortable Experience in the context of IoV

Comfortable Experience applications provide drivers with entertainment services such as Web connectivity and audio and video streaming. Comfortable Experience services can be categorized as follows:

Comfortable Experience provides drivers with:

1. Remote Vehicle Personalization/Diagnostics: It aids in downloading customized vehicle settings and uploading vehicle diagnostics from/to the infrastructure.
2. Internet Access: Vehicles can connect to the Internet through an RSU if the RSU is working as a router.
3. Digital Map Downloading: Drivers may obtain maps of regions according to their requirements before traveling somewhere new or for guidance as they travel. Also, map database content downloading acts as a portal for accessing valuable information from mobile hot spots or home stations.
4. Real-Time Video Relay: Passengers' on-demand movie experience will not be limited to their options at home. The driver can request real-time video relay of his/her favorite movies.

Table 8 lists papers that discuss the driver's Comfortable Experience as an application of IoV.

5.5 Advertisements and Commercials: Three papers have addressed the concept of Advertisements and Commercials in the context of IoV

This concept is specific to promoters and service providers as a strategy for drawing customers to their stores. The goal is to advertise gas stations or highway restaurants, for example, or to enable businesses to advertise their services to drivers within communication range.

Table 8 lists papers that discuss Advertisements and Commercials as an application of IoV.

5.6 Smart Parking: 36 papers have addressed the concept of Smart Parking in the context of IoV

Informing drivers of the availability of parking in large metropolitan areas lets them know about the availability of slots in parking lots in specific regions.

Other locations such as restaurants, hotels, malls and government buildings can be assessed in terms of the locations of the various parked cars in a given lot and the number of vacant parking spaces, thereby saving drivers time on the road.

Table 8 lists papers that discuss Smart Parking as an application of IoV.

5.7 Smart Traffic Lights: 20 papers have addressed the concept of Smart Traffic Lights in the context of IoV

Traffic lights can be controlled to prioritize certain lanes whenever other lanes are empty. In the event of a traffic jam, the service lane can be used as an extra traffic lane. Figure 5 presents the number of scientific papers published per category of IoV applications.

6 Open source software for IoV

As indicated in Table 9, OSS deployment under the simulation category in IoV software is erratic.

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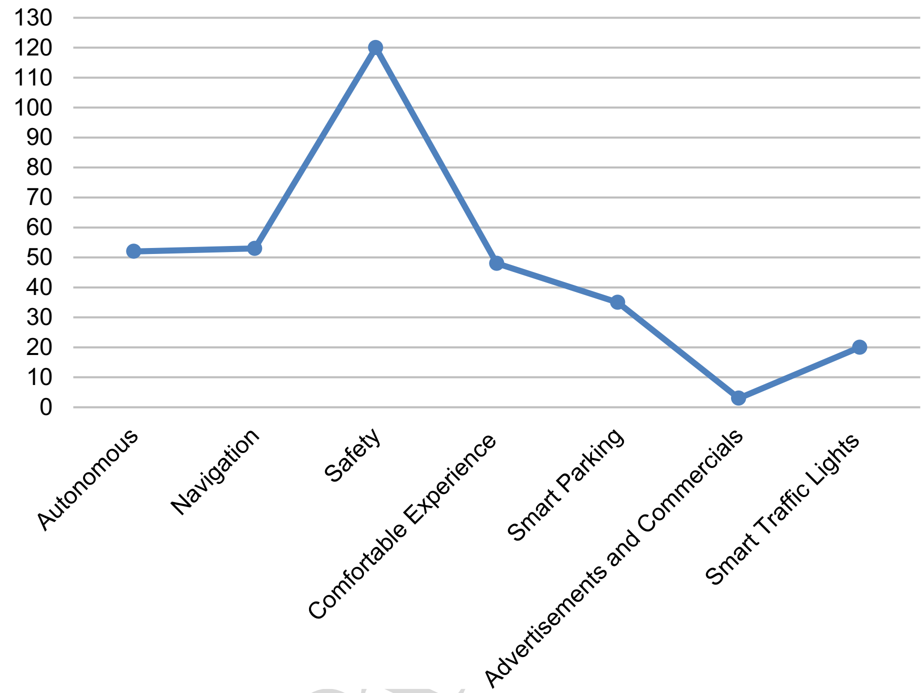

Fig. 5 Number of papers per category of IoV applications

The OSS community would benefit from consolidating its efforts in the development of standardized solutions tailored to users' requirements in order to avoid such an amalgam of products. Figure 6 highlights the number of OSS vs Commercial Software Deployed in IoV Software.

7 Challenges of IoV

Currently, IoV is the subject of numerous research projects, their main emphasis being how to ensure reliable and effective wireless connections among vehicles. The most awkward challenge faced by the OSS community is the security of connected vehicular environments; other challenges involve scalability, standardization and others.

7.1 Scalability

Due to the huge number of cars on the roads and the overload of communication, a great many new connection points will need to emerge, given the vast amount of data that will need to be transmitted and processed seamlessly and in real time. To cope with this influx of new information, cities, governments and the OSS community need to make sure they have a fast, scalable and secure network in place. Failure to do so could result in missing out on the benefits of driverless and connected vehicles, regardless of how refined the technology within the actual vehicle might be.

7.2 Intelligence

Vehicles should be equipped with intelligent software to handle the high level of multitasking required, software that uses high-end microcontrollers and processors, in addition to high computing power.

7.3 Security and Privacy

Automakers are attempting to make their vehicles more secure in this era of Internet-connected devices. While vehicles that access the Internet enable services like infotainment systems and maintenance monitoring, they also present security risks on account of being connected to the Web [27]. Security and Privacy IoV systems use an ad hoc network to send data back and forth [68], data such as location, speed, direction, vehicle type and vehicle owner. Moreover, there is a trade-off involved in encrypting the data versus the responsiveness of a real-time system, since encrypting messages requires more network and processing resources.

7.4 Connectivity and Big Data

Connecting significantly heterogeneous IoV devices is a major challenge when it comes to vehicles on roads, with all their intersections, buildings and communication devices. For example, as vehicles move at high velocity, connections may break, or packet loss may occur, reducing the efficiency. The size of data in IoV may need to increase dramatically,

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Table 9 List of open source and commercial software deployed in IoV

Category of IoV software	Description	List of OSS found	List of commercial software
V2X	V2X constitutes the infrastructure and the backbone of the IoV system; it is the core layers and protocols [34]	1. Open vSwitch 2. Arduino Based 3. RaspberryPi	1. Audi's ACC 2. NEC CAR
Simulation	A testing environment for both network and mobility behavior to predict errors and flaws	1. SUMO [4, 5, 13, 14, 20, 21, 23–31] 2. MOVE [4, 5, 13, 14, 109] 3. CityMob [4, 14] 4. STRAW [4, 13, 14] 5. FreeSim [4] 6. Netstream [4, 14] 7. VanetMobiSim [4, 5, 12–15, 70] 8. ns-2 [4, 5, 12–17] 9. GloMoSim [4, 13, 14, 17] 10. SNS [4, 14] 11. JiST/SWANS [4, 13, 14, 27, 83], 12. GTNetS [4, 14] 13. TraNS [4, 13, 14, 16] 14. NCTUns [4, 13, 14, 16, 153] 15. GrooveNet [4, 14, 152] 16. MobiREAL [4, 13, 14] 17. OMNET++ [5, 13, 14, 16, 17, 21–23, 25–28, 31, 38, 39, 110] 18. Veins [5, 14, 21, 24, 27, 30, 31, 110] 19. Voronoi [145, [146] 20. NS3 [16, 79, 125] 21. iTETRIS [27, 115, 142, 153] 22. TRAFFSIM [24] 23. MovSim [24] 24. V2X [75, 92] 25. Shawn [27] 26. AIMSUN [98] 27. MixMobGen [7] 28. GEMM [13] 29. AutoMesh [13] 30. CARISMA [8, 13] 31. VGrid [13] 32. Gorgorin [13] 33. BonnMotion [13] 34. J-SIM [14]	1. ABSCEV [89] 2. Toyota Prius 3. TSIS-CORSIM [4, 13, 14] 4. Paramics [4, 13, 14] 5. Daimler-Chrysler [4] 6. Farsi and Videlio [4] 7. Carisma [4, 155] 8. VISSIM [4, 13, 14, 24, 113, 124] 9. QualNet [4, 13, 17] 10. OPNET [4, 17, 67]
Services	Platforms the user interacts with, like navigation apps	1. KAA Project [9] 2. Artery [32] 3. OpenMotors [10] 4. OpenXC [151] 5. OpenDayLight [156] 6. Automotive Grade Linux [18]	1. Apple Car Play [11] 2. Lubao (Tencent) [157]
Cloud	Cloud management applications for cloud computing and big data management	1. Smart ITS [71] 2. Android [70, 109, 114, 151]	

which in turn would make effective management in terms of credibility and security especially difficult.

7.5 Performance

Wireless devices are restricted by interference, capacity, redundant transmission and self-competition, which results in transmission delays, data collisions and packet loss, affecting the performance of different applications. It should be mentioned that it is not feasible to increase the available bandwidth, because only a small part of the wireless range is allowed for connected vehicles.

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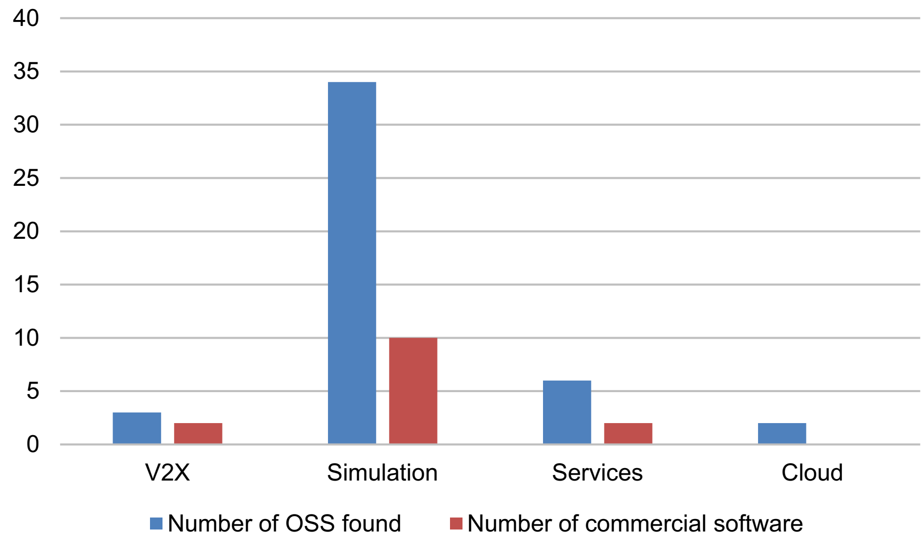

Fig. 6 OSS versus commercial software deployed in IoV software

7.6 Reliability

It is extremely difficult to fully design a system that can make driving safer, since sensors are susceptible to degradation and loss of efficiency over time, leading to flaws in automated vehicles that can be dangerous for pedestrians and cause mishaps that can be very costly in terms of human lives [69, 70].

7.7 Standardization

A lack of standards causes a lack of coordination and communication, which makes scaling more difficult. Companies are not willing to adhere to pre-defined standards, claiming that standardization can hinder beneficial market positioning as well as new, compelling opportunities. The OSS community can play a major role in the area of standardization, since it has no lucrative interest. Figure 7 depicts the number of papers that tackles IoV challenges.

Besides, Table 10 provides a description of each challenge as well as a non-exhaustive list of papers that address these challenges.

8 Opportunities in Using OSS Applications as IoV

The availability of OSS for IoV occasions opportunities for different OSS categories to be deployed in various applications. Moreover, OSS categories aim to solve specific challenges that arise with IoV implementation. After conducting an extensive review of the literature, this section provides a map of OSS groupings and their possible corresponding applications or challenges they can solve.

8.1 Autonomy

Autonomous technology has made noteworthy advances in the industry sector ever since prototypes for self-driving cars were exhibited during the DARPA Urban Grand Challenge [71]. Nowadays, several companies oriented toward urban-area autonomous cars have followed in the footsteps of that DARPA Urban Challenge achievement. Autoware is now used by more than one hundred companies and thirty vehicles [72]. In fact, that very DARPA Urban Grand Challenge project inspired its design concept. Contributions from the OSS community in this category could include Apollo and PolySync, which are both comparable to Autoware [73]. Baidu's alliance initiated Apollo, which relies on GNSS high-precision positioning and 3D perception. Alternatively, PolySync offers an integrated development environment for the autonomous technology's backend framework. Both projects are able to consider specific algorithms and platform configurations. However, Autoware is designed and implemented for a rather wide range of configurations, allowing users to select algorithms and platforms as per their requirements. The general openness and purposiveness of Autoware have simplified its integration, while Udacity has laid the foundation for online education in autonomous technology. It likewise facilitated the production of self-driving vehicle platforms such as AutonomouStuff platforms [74]. Shinpei Kato et al. [71] have succeeded in testing their autonomous technology on embedded systems, noting that there is still work to be done in terms of testing the complete software stack developed on top of real-time and embedded systems and in terms of quantifying its performance using real-time compatible hardware.

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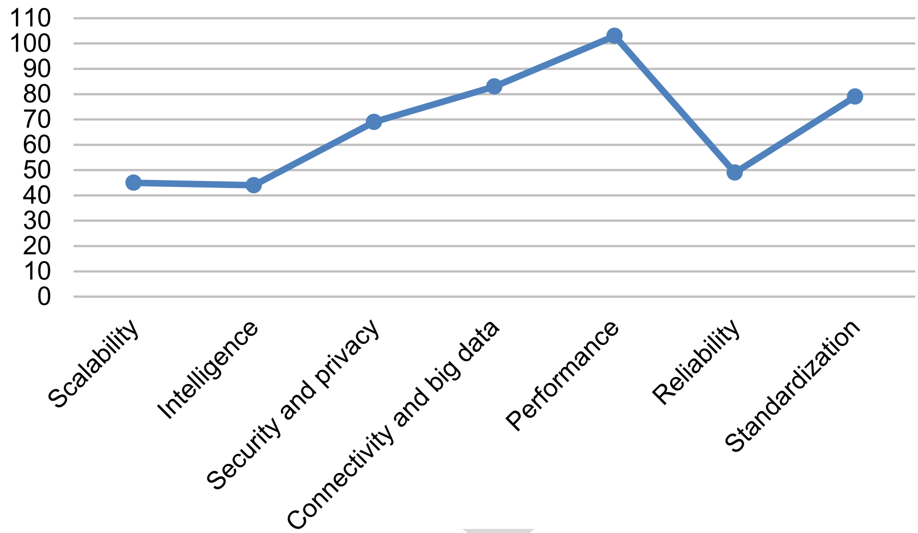

Fig. 7 Number of papers that tackle IoV challenges

Table 10 A non-exhaustive list of papers that address the challenges of IoV

Challenge	Description	Reference to papers
Scalability	A huge number of new connection points and a vast amount of data that will need to be transmitted and processed	[1, 2, 5–7, 13–15, 17, 19, 22, 26, 31, 40, 41, 43, 50, 53, 55, 62, 64, 77, 80, 81, 83, 84, 91, 96, 98, 100, 101, 104, 109, 115, 116, 124–126, 131, 157]
Intelligence	Software with the ability to handle visual processing, distance calculation, packet response and self-navigation	[1, 2, 14, 21, 22, 24, 26, 30, 31, 35, 39, 41, 53, 64–67, 69, 70, 72, 73, 75, 76, 81, 82, 84, 88, 89, 91, 96, 99–101, 104, 105, 111, 112, 114, 124, 126, 127, 131]
Security and privacy	Security risks on the account of being connected to the Web	[1–3, 5, 6, 12, 14, 15, 17, 18, 20, 22, 24–26, 28, 30–32, 35, 38–41, 45, 62, 64, 70, 72, 73, 75–77, 79, 80, 82–89, 91, 95, 98–100, 103–105, 107, 109, 111, 115, 116, 124, 126, 127, 130, 131, 133, 147, 157]
Connectivity and big data	The unequal density and large distribution of vehicles in the city, architectural obstacles and added interference from other communication technology sources will make the connectivity inadequate	[1–4, 6, 12–22, 24–26, 31, 32, 35, 38, 39, 41, 44, 45, 50, 53, 60, 62, 64, 67–70, 72, 73, 75–77, 79–85, 89, 91–94, 96–100, 103–105, 107–109, 111, 112, 114–116, 119, 122, 124, 126, 127, 131]
Performance	Different qualities and response times, security, connectivity and big data cause a huge reduction in performance	[1–6, 10, 12–22, 24–26, 28, 30–35, 38–41, 43–45, 49, 50, 53–55, 57, 58, 60, 62, 64–70, 72, 73, 75–77, 79–85, 87–101, 103–105, 107, 109–112, 114–116, 119, 122–127, 129–131, 133, 135, 139, 147]
Reliability	Faults and accidents due to the degradation of embedded sensors	[1, 2, 6, 14, 17–19, 22, 24–26, 30, 33, 35, 49, 53, 54, 62, 64, 67, 69, 70, 72, 77, 79–82, 84, 88, 90, 91, 94, 97, 98, 100, 101, 103, 105, 108, 110, 112, 115, 119, 122, 124, 125, 133, 135]
Standardization	Lack of standards causes lack of coordination and communication	[1–3, 6, 7, 13–16, 18–22, 24–26, 28, 30, 31, 34, 38–41, 43, 45, 49, 50, 53–55, 57, 58, 60, 62, 64, 65, 67, 70, 72, 73, 75–77, 79–82, 85, 91–94, 96, 98, 100, 101, 103–105, 107, 109, 110, 112, 114, 116, 119, 122–127, 129–131, 133, 135, 147]

8.2 Navigation

Navigation systems for automobiles are the result of various technologies, many of which have been around for years, yet were inaccessible or too costly. Restrictions such as power processing, batteries and user interface have to be fixed before a product can be commercially viable. The OSS community has developed *Navit*, car navigation software for Widows, Linux OS and portable media [75]. It displays the positions of cars in 3D visualization or bird's-eye view mode on a map generated from GPS data and can offer accurate route estimations, supports Points of Interest (POIs) and provides touch screen functionalities that can be added via a usable plug-in system. *Navit* maps are created in real time from vector data, unlike many other navigation systems. *Navit* is entirely offline and can work while being disconnected from Internet. Waze is another alternative application for social GPS navigation. It uses real-time maps and traffic updates to improve drivers' daily commutes. In response to the rising need for high-quality, accurate maps, OsmAnd was developed, a navigation app that includes a map and access to OpenStreetMap data. It is a worldwide, free and high-quality map application [76].

8.3 Safety

When automotive safety is a function of software, the issue of software security becomes paramount, particularly when it comes to new areas of technology and research such as connected cars. *NS-2* is an open source network simulator. It is commonly used in safety applications for VANETs and in studies on wireless communication [77].

8.4 Comfortable Experience

The user's overall experience includes network games, inter-vehicle chat, electronic messaging, mobile access to the Internet and other information and communication services.

An association of three universities and six manufacturers has introduced the *FleetNet* project, also called *Internet on the Road* [78]. Its objective is to provide a communication platform for vehicle networks and to normalize the suggested solutions for enhancing drivers' and passengers' comfort and security.

8.5 Advertisements

Although the dashboard acts as a central hub for controlling everything in a car, it is also prime real estate for advertisers. *OpenX* is an OS rotating advertisement system specifically for ads related to hospitality services [79]. It uses a rotational system where no two ads are shown together but also fails if there are not enough ads to be displayed. Another OS option is provided by *ReviveAdServer,* which enables advertisers, publishers and ad networks to advertise on apps, Web sites and video games, and to gather thorough information about clicks and impressions [80]. Contextual marketing is a popular focus nowadays and has proven ideal for marketers in the sense that their targeted audience is more likely to make a purchase. The concept is being implemented by *Aha Radio*, using audio advertising. Location-based offers are sent to the corresponding in-dash systems [81].

8.6 Smart Parking

This functionality collects information about the availability of spaces in parking lots and synchronizes between vehicles to direct them to free spaces. *ParknCloud* is an OS SaaS [82]. Google Cloud Infrastructure hosts it, which ensures a high level of security, reliability, flexibility and support to its many users.

8.7 Smart Traffic Lights

Simulations usually serve to test new systems before their deployment in the real world. To show their capacity to improve traffic flow, Daniel Krajzewicz et al. [75] have implemented an agent-based algorithm for traffic light controls with SUMO. SUMO is an OSS package for road traffic simulation [83].

8.8 Scalability

Studying comprehensive scenarios in connected vehicles is very important for communication protocols design and applications. Because the operation and management of a huge number of real nodes is impractical, simulation is the most effective method for assessing such comprehensive scenarios. Fernandes et al.'s findings demonstrate that the suggested *NS-3* optimization results in substantial performance enhancements with respect to memory usage and execution time. This allowed NS-3 to execute simulations involving around 10,000 nodes [84].

8.9 Intelligence

There is tremendous opportunity where OS is concerned for integrating intelligent systems and algorithms in connected cars. For instance, traffic congestion has been troubling drivers for years, and it only seems to be getting worse as the population increases, leading to a higher number of vehicles on the roads. Levinson et al. proposed in their research to reduce the flow of traffic by using vehicular ad hoc networks (VANETs) and artificial intelligence to develop support for drivers that helps to resolve traffic congestion [85].

8.10 Location Accuracy

Most connected vehicles software requires that every vehicle recognize its exact current location in real time. GPS is the most widely known positioning technique for connected vehicles. Mohamed et al. [86] recommend positioning techniques which can be used with DGPS, in order to deliver a constant and reliable real-time localization service with the appealing characteristics of being reliable, precise, inexpensive and operable in real time in different areas.

8.11 Connectivity and Big Data

The development of connected vehicles requires the usage of a complex computational framework to gather and analyze a huge volume of data produced by many kinds of vehicle operations, using the technologies of Big Data. Given that these data are vital for numerous connected vehicles applications, the development and control of MapReduce algorithms for

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data processing of vehicles, using the framework of Hadoop, has led to the creation of a host for data source analytics [87]. This host permits the whole ecosystem of industry in the field of connected cars to access the valuable data they require in order to develop applications for connected cars.

8.12 Performance

Tools to assess the vehicular networks' performance are required for an efficient deployment of IoV. Many traffic simulators were built under the initiative of Intelligent Transport System with a main focus on forecasting and modeling the flow of vehicular traffic and congestion from a queuing viewpoint. Accurate speed, traffic density, distance and models of communication are imperative for evaluating the scalability and performance of protocols for intravehicular communication. Rahul Mangharam et al. invented *GrooveSim*, a geographic routing simulator in vehicular networks, to tackle the need for a reliable, user-friendly and realistic network and traffic simulator. GrooveSim's simulation models, confirmed with field tests, helped to evaluate vehicular network performance in different scenarios [88].

8.13 Reliability

Since communication between vehicles is possible through the mobile Internet, the system should aim to achieve secure commuting and to ensure road safety. Thus, network survivability and reliability become issues of top concern. Vehicles in Network Simulation (*Veins*) is an OSS tool to realize VANETs. It is built using Simulation of Urban Mobility (*SUMO*) and renowned network simulator *OMNeT++*. At the microscopic level, SUMO generates a representation of road traffic. Veins also uses some Mixed Simulator (*MiXiM*) features such as interference estimation and radio wave propagation, for a more reliable simulation [42].

8.14 Standardization

With the rapid development of connected cars, technologists recognize that there is an emerging need for standards. Autonomous devices need to be able to communicate with one another regardless of any proprietary platform or underlying technology. Governments have recognized the need for this as well, and now industry has stepped up to offer a solution. *Automotive Grade Linux* has been working to ensure the widespread use of OSS by providing one of the largest software resource platforms [18].

9 Areas Where OSS Can Make A Difference in the IoV Field

9.1 Road Safety Applications

One of the major usages of IoV applications is to ensure driver safety; safety applications are of vital importance for significantly reducing the number of accidents. For this purpose, applications such as speed control and collision avoidance are used, in addition to anti-theft mechanisms and home-monitoring systems to track the location of one's car from home. [54].

10 Post-crash Notification (PCN)

With PCN, when an accident occurs, the car will send alert messages to nearby vehicles, enabling them to make a timely decision. A PCN application could be deployed using V2I and V2V configurations. Indeed, V2V has the benefit of rapidly providing information through a discover-and-share policy. With the help of reliable sensors that assist in determining likely changes in the driver's behavior (e.g., sudden changes in direction, hitting the brakes abruptly, etc.), these are broadcast back over beam antennas to other vehicles going in the same direction. Upon reception, an adjacent vehicle may share this information with the other available nodes, with a flooding mechanism for routing. The PCN application relies on the standards of communication established for WAVE (Wireless Access in Vehicular Environments). As a safety application, the aim is to alert nearby vehicles of accidents and road conditions to allow drivers to take the appropriate decisions and take action before or after being informed of hazardous circumstances [89]. The spatial distance of interest for these types of applications is typically up to 1500 m; additionally, the messages necessitate high priority status and an extremely low communication latency, less than 100 ms. One major obstacle involves the particular case of false alerts initiated by a vehicle that may be engaging in unusual driving behavior, causing this information to flood the IoV network. It is imperative that the OSS community address the issue of false alarms.

11 Lane Change Assistance (LCA)

Changing lanes is a driving maneuver considered to be high risk in terms of its rate of error. Drivers need to be able to preclude any risk to others on the road when making a lane change. If a driver neglects to look over their shoulder, or if their rearview mirrors are not positioned properly, or if the driver is simply distracted, they may at a crucial moment fail to notice other vehicles in their blind spot. Another common cause of accidents when switching lanes is misjudging the speed of lane-adjacent vehicles [29]. If a lane change is initiated under such hazardous circumstances, a collision with a vehicle in the adjacent lane is more likely to occur. Of particular importance for the OSS community is to tackle the aforementioned problems and bring improvements to lane change assistance applications accordingly. If the sensory system's monitoring of the area surrounding the vehicle demonstrates that a lane change could potentially be dangerous, then the driver needs to be warned about this in a fitting and timely manner. The warning information may be transmitted optically, acoustically, or to the tactile senses.

11.1 Traffic Management Applications

Road congestion is a prevalent concern in connection with growing urbanization in developing and developed economies. Applications that achieve effective management of road traffic aim primarily to optimize drivers' travel times and to prevent traffic jam situations.

12 Navigation: Congestion Road Notification (CRN)

CRN identifies and informs drivers about road congestion and is a useful application for planning one's commute and route [90]. This type of application is classified among existing GPS-based applications that suggest a new route when a certain route happens to be congested. Nowadays, many road assistance tools exist on the market for smartphones and other smart devices. They depend on GPS coordinates and can determine the fastest or shortest path from a starting point to the intended destination by taking into account one-way streets and so forth. OSS solutions in this area do not compete with commercial ones, making CRN a niche to consider.

13 Smart Vehicle Parking

Be it for restaurants, hotels, malls or government buildings, a smart parking assist system can identify the locations of cars in parking lots and count the vacant parking spaces, easing the often time-consuming search for parking. This is done by guiding drivers directly to areas with available parking spaces. Additionally, parking assistance systems automatically and accurately guide the vehicle into and out of tricky or tight parking spaces. For increased safety, the parking assistance system also maneuvers an emergency braking function if the ultrasonic sensors detect an obstacle, first by warning the driver of a potential collision, or even by automatically activating the brake when necessary. ParknCloud is an innovative OSS that allows users to pay for parking and municipalities to manage parking areas and rates [82]. Few similar applications are needed as a contingency plan in the case that ParknCloud becomes a commercial application.

13.1 Comfort and Infotainment Applications

Non-safety applications tend to require diverse communication features, from high QoS requirements for interactive entertainment and multimedia applications, to no specific demands for real-time applications providing traveler information and support [91]. Generally, this application category is driven by passengers' need to communicate with ground-based destinations like the PSTN (Public Switched Telephone Network) or with other vehicles.

14 Energy Optimization and Emission Reduction

The constant growth in the number of vehicles on the roads means that the high flow of vehicular traffic has become a public problem for governmental institutions to tackle and for people in general, since travel time, gasoline consumption and greenhouse gas [GHG] emissions have seen a significant increase. Policies need to be instituted and action needs to be taken to reduce the environmental and social impact of such an increase. In this context, Orozco et al. have developed an application for VANET simulation using two software applications: SUMO and OMNeT++. The application they proposed optimizes fuel consumption and reduces GHG emissions, proving that vehicles at a preset speed show a significant decrease in their gasoline consumption and GHG emissions compared to vehicles not operating at that speed [101].

15 Comfortable Passenger Experience

Users can access the Internet using V2I communications; hence, business activities can be carried out in a vehicular environment, by applying the mobile office concept. Streaming of mobile media in vehicles may likewise be possible, making extended commutes more enjoyable. A clear objective is to implement a graphical user interface for vehicles, such as color reconfigurable head-up and head-down displays, and large touch screen active matrix LCDs (liquid crystal displays), for an exciting video-streaming experience. Passengers can enjoy their commute using real-time applications such as online gaming and video streaming or using customized terminals installed next to their seats. This is another area in which the OSS community could potentially develop a great deal of alternative solutions.

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16 Conclusion

Vehicles have evolved to comprise intricate systems involving several hundreds of computers or information processing units that rely on the millions of lines of code that run different kinds of software. OSS is omnipresent at each layer of IoV architecture. However, its presence is, at times, either erratic or weak. This study presented the state of the art of OSS deployment within IoV architecture in the aim of improving the efficiency of OSS deployment in the IoV field. It has been observed that at the Physical World Layer, the OSS community might consider developing and deploying solutions for CIP and I2C protocols. The development of OSS solutions for WME protocol at the gateway layer is recommended. Furthermore, there is erratic deployment of OSS solutions for QoS and Communication protocol types. At the fog layer, the OSS community might consider developing and deploying solutions for WiMax and LPWAN protocols. There also exists erratic deployment of OSS solutions for TCP, STCP and UDP protocols. It would be beneficial, therefore, for OSS experts to develop more standardized solutions for QoS, Communication, TCP, STCP and UDP protocols that meet most of the users' requirements. At the cloud layer, the OSS community might consider deploying solutions in the Infrastructure as a Service and the Service-Oriented Architectures categories. OSS deployment in the simulation category of IoV software is erratic as well. The OSS community could consolidate its efforts to develop standardized solutions tailored to users' requirements in order to avoid an amalgam of products in this category.

Apollo software relies on high-precision GNSS localization and 3D perception. PolySync offers an integrated development environment for the backend framework of driverless technology. Both Apollo and PolySync are able to consider specific algorithms and platform configurations.

Furthermore, this study has highlighted that there exist many solutions, such as the tools listed below, that can serve as references for an efficient deployment of OSS in the context of IoV.

Navit has emerged as car navigation OSS for Windows, Linux OS and portable media. Another existing alternative is Waze, navigation software for social GPS that uses maps to deliver real-time traffic updates, helping drivers with their everyday commutes. In response to the growing demand for high quality, accurate maps, OsmAnd was developed, a map and navigation application with free access to worldwide editable OpenStreetMap data. NS-2 is an OS network simulator that is commonly used for safety applications in VANETs and in studies on wireless communication. The FleetNet project also known as Internet on the Road has for its objective to provide a communication platform for vehicle networks and to normalize the suggested solutions for enhancing drivers' and passengers' comfort and security.

Openads is an OS rotating advertisement system specifically for ads related to hospitality services. Another OS option is provided by ReviveAdServer, which helps advertisers, publishers and ad networks to advertise on apps, Web sites and video games, and gather thorough information about clicks and impressions. ParknCloud is an OS SaaS. Google Cloud Infrastructure hosts it, which ensures a high level of security, reliability, flexibility and support to its many users. The proposed *NS-3* optimization resulted in substantial performance enhancements with respect to memory usage and execution time.

There is tremendous opportunity where OS is concerned for integrating intelligent systems and algorithms in connected cars. For instance, traffic congestion has been troubling drivers for years, and it only seems to be getting worse as the population increases, leading to a higher number of vehicles on roads. Positioning techniques can be used with DGPS in order to deliver a constant and reliable real-time localization service with the appealing characteristics of being reliable, precise, inexpensive and operable in real-time in different areas.

Given that the huge volume of data produced by many kinds of vehicle operations are vital for numerous connected vehicles applications, the development and control of MapReduce algorithms for data processing of vehicles, using the framework of Hadoop, has led to the creation of a host for data source analytics.

This host permits the whole ecosystem of industry in the field of connected cars to access the valuable data they require in order to develop applications for connected cars.

GrooveSim, a geographic routing simulator in vehicular networks, tackles the need for a reliable, user-friendly and realistic network and traffic simulator. These simulation models, confirmed with field tests, help to evaluate vehicular network performance in different scenarios.

Vehicles in Network Simulation (Veins) is an OSS tool to realize VANETs. It is built using Simulation of Urban Mobility (SUMO) and renowned network simulator OMNeT++. At the microscopic level, SUMO generates a representation of road traffic. Veins also uses some Mixed Simulator (MiXiM) features such as interference estimation and radio wave propagation, for a more reliable simulation.

Automotive Grade Linux has been working to ensure the wide use of OSS by providing one of the largest software resource platforms.

Areas of future study include standardization and a consolidation of the OSS community's efforts to provide efficient solutions for IoV. Another future study will bear upon OSS usage in the Internet of Things.

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