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A seven-layered model architecture for Internet of Vehicles

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ABSTRACT

In the last decade, many vehicles which contain components to monitor different conditions (such as driver monitoring, tire pressure, oil pressure, vehicle speed, acceleration and position) have emerged. Internet of Things (IoT) is enabling the collection of different types of information from a given environment. The integration of results from both trends has led to the emergence of the concept of Internet of Vehicles (IoV). The implementation of IoV requires devices (sensors, personal devices, actuators, among others) to communicate with other devices and the infrastructure using different technologies. Such device interactions face several design challenges such as incompatibility among the devices, different qualities and response times for the Internet connection, limited processing and storage capabilities. To address these challenges, we propose a comprehensive framework that supports a layered design architecture capable of providing seamless integration for inter-device communication into the IoV ecosystem. We also present a review of recently proposed IoV architectures and discuss their salient differences with our proposed architecture.

1. Introduction

In the last decade, the number of vehicles worldwide has increased from around 900 million in 2006 to over 1 billion in 2014 (McKinsey & Company, 2013; OICA, 2015), and is expected to reach 2 billion by 2035 (Yang, Wang, Li, Liu, & Sun, 2014). Many such vehicles will be connected cars which can communicate wirelessly (Statista, 2012) with various types of devices (sensors, phones, cameras) connected to the Internet, devices in the car (intra-vehicular) or outside of the car (inter-vehicular), using a wide range of communication protocols and transmission media. Moreover, researchers have predicted that 25 billion devices will be connected to the Internet by 2020 (Yang et al., 2014) which open further challenges such as pollution, road safety and efficiency of network infrastructures.

Connected vehicles and devices are integral components of the Internet of Vehicles (IoV) concept which is a mobile system which allows information exchanges involving Vehicle to Vehicle (V2V), Vehicle and Roadside (V&R), Vehicle and Device (V&D), Vehicle and Person (V&P) and Device to Device (D2D) (Nanjie, 2011). IoV promotes strong...
interactions between humans and vehicles along and aims to improve human abilities (such as vision, hearing, sensitivity or spatial awareness), experiences, safety, energy and vehicles intelligence, which in turn will influence different markets, including consumer lifestyle, consumer vehicle market and even consumer behaviour modes (APEC, 2014; McKinsey & Company, 2013). The implementation of IoV requires devices to communicate and interact with other devices and infrastructure using different technologies depending on the device’s type (sensor, personal communication device, tablet), network type (Wireless Sensor Network (WSN), Personal Area Network (PAN) and so on) and their specific characteristics, thereby presenting a complex interaction scenario where multiple challenges need to be addressed. These challenges include: incompatibility among the devices, different qualities and response times for Internet connections and limited access to data processing and storing services. As such, seamless IoV integration with the existing network (cellular, WiFi, Long-Term Evolution (LTE)), emerging technologies (Internet of Things (IoT), Intelligent Transportation Systems (ITS), Connected vehicles and Cloud Computing) and transportation infrastructures (traffic lights, signs and roadside units (RSUs)) is necessary to enable efficient communications in the IoV environment (Guerrero-Ibanez, Zeadally, & Contreras-Castillo, 2015). In this context, in this work, we propose a seven-layered architecture that includes a D2D interaction model which supports the functionalities, interactions, representations and information exchanges among all the devices making up the IoV ecosystem.

The rest of the paper is organized as follows. Section II presents a review of current literature on IoV architectures along with their strengths and shortcomings. We describe our proposed seven-layered IoV architecture in section III. Finally, we make some concluding remarks in section IV.

2. Related works: previously proposed architectures of IoV

One of the main trends within IoV environments has been to address communication issues among heterogeneous devices in different specific domains, such as traffic control, safety and infotainment. However, these applications have limitations in their interoperability because of privacy, accessibility and availability issues which is why they tend to operate as independent entities. There have been several attempts (Bonomi, 2013; Nanjie, 2011; Wan, Zhang, Zhao, Yang, & Lloret, 2014) to minimize such application silos and increase interoperability. These attempts have focused on the development of multi-platform interaction frameworks that allow different vehicles’ elements and devices to interact in an IoV environment.

In Nanjie (2011), the authors proposed a three-layered architecture (client, connection, cloud) for ITS. In the client layer, all sensors inside and outside of the vehicle responsible for vehicle speed, position, tire pressure, oil pressure, proximity, pollution levels, noise, collision detection, forward obstacle, side obstacle, road-to-vehicle and road condition are responsible for capturing all the information concerning the events that occur in the vehicle, including driving patterns as well as intra and inter-vehicular connections with other cars. The connection layer ensures interoperability with all the available networks to support all the communication models (V2V, V&R, V&P, V&I). It sends all the information to the cloud layer which will provide the required computational power needed to satisfy
all the vehicles’ requirements such as sharing of communication spectrum, data storage, search and analysis of information.

In Wan et al. (2014), the authors also presented a three-layered architecture (vehicular, location and cloud). The vehicular layer manages all the vehicle’s internal sensors and is responsible for acquiring information such as ambient and physiological parameters (e.g. blood pressure, heart rate, mood behaviour) of car’s occupants through short-range wireless technology. This architecture enables the exchange of information with nearby cars. In the case of cars that are out of range, exchange of information is achieved by using multi-hop communications with the support from roadside communication infrastructures (e.g. RSUs). The cloud layer hosts services that provide access to historical traffic information. In addition, this layer allows load balancing across multiple interconnected cloud systems.

In Bonomi (2013), the authors proposed a four-layered architecture for IoV. The first layer covers vehicles, communication software mainly for V2V and communication links using the 802.11p protocol. The second layer, called infrastructure, defines the technologies that allow connectivity among all the participants in the IoV ecosystem in which the vehicle is located at any given time. The operation layer is the third layer. It verifies and ensures compliance with all applicable policies to regulate the information management and flow. The fourth layer which is the cloud layer indicates the type of cloud (public, private or business) based on a defined profile coupled with the possibility of receiving services (voice, enterprise video and data) on demand.

In Gandotra, Khumar Ja, and Jain (2017), the authors proposed a three-layered architecture for D2D communication. The first layer represents the network area in which devices are either directly connected to each other or through gateways with the network management selecting the type of communication (wired or wireless). The second layer supports IP connectivity and roaming. Finally, the third layer contains the selected application (IoV, smart homes and so on).

In Kaiwartya et al. (2016), the authors proposed a five-layered architecture that includes perception, coordination, artificial intelligence, application and business. The perception layer represents the different types of sensors and actuators integrated into vehicles that collect information from the various elements of the vehicle, traffic environment and connected devices (smartphones, tablets, headphones, smartwatches). The coordination layer makes use of a universal coordination module for network communications and ensures the secure transfer of information that needs to be processed in the cloud infrastructure. The cloud is responsible for storing, processing and analysing the information from the other layers to make informed decisions on the selection of the best applications for traffic safety, multimedia and Information, intelligent services, and critical analysis of the information received. The business layer applies statistical analysis to come up with strategies (using graphs, flowcharts and comparison tables (usage of data, pricing budget preparation) that can be used to develop a business model. From Table 1, we note that many of the previously proposed IoV architectures in the literature recently present layered models with very general layers and objectives. These models do not really define the actual protocols and functions of each layer in detail. We argue that it is necessary to define more layers to reduce the complexity of each layer and standardize the interfaces and protocols used in each layer. By doing so, we will simplify the development of a modular IoV architecture that guarantees strong interoperability among the different technologies.
3. Proposed IoV architecture

One of the biggest challenges of IoV is the seamless integration of all components (vehicles, sensors and actuators, communication and roadside infrastructures, personal devices and humans) to improve safety, comfort and traffic condition levels. This task requires the development of a set of requirements and functionalities that can be encapsulated as a layer in a layered-based IoV architecture. The main challenge in a layered design architecture is the optimal number of layers and the capabilities for each layer, including: network characteristics (interoperability, scalability, reliability, modularity among others), communication technologies (Wi-Fi, Bluetooth, Zigbee, 4G/LTE, etc.), data security (confidentiality, integrity, availability, authentication and identification) and user interaction (visual, haptic, audio). In Kaiwartya et al. (2016), the authors identified several issues that need to be considered when designing an IoV-layered architecture. These issues include: (a) interconnecting devices to heterogeneous networks, (2) flexible adaptation to new technologies and (3) Internet integration, service-oriented architecture and plug-and-play-based interface.

We propose a comprehensive framework that focuses on interaction and network models. The framework is based on a layered architecture aimed at providing a seamless integration for inter-device communication in the IoV ecosystem. The detailed description of the control and management and data processing layers are beyond the scope of this paper. However, we still provide some basic information about these layers below.

3.1. Interaction model in IoV

An IoV ecosystem is composed of six main components that interact with each other and they are: vehicle (V), person (P), personal device (P), network infrastructure (I), sensing device (S) and roadside device (R). Vehicle includes all nearby vehicles which can establish a communication link to exchange relevant information (OLCA, 2015) (traffic conditions, alerts, physical variables and so on) in the IoV ecosystem. Person includes people that request or access a service in the IoV environment. Personal device is a device that belongs to a person (driver, passenger, pedestrian, cyclist) and uses or provides a service in the IoV environment. Network infrastructure refers to all devices in the
network that are used to send data. Sensing device refers to sensors and actuators that collect information about the vehicle’s parameters (tire pressure, fuel consumption, vehicle temperature, etc.), person’s health levels (blood pressure, heart rate, blood oxygen level, among others) and environmental variables (pollution, noise level, weather conditions). Finally, roadside device is the transportation system infrastructure such as traffic lights, information screens or radars that have the capability to disseminate relevant information about traffic jams, accidents or possible detours.

Different interactions among all IoV elements will cause a multi-level data exchange (vehicle-vehicle, vehicle-device, device-device, person-vehicle, person-device) for in-vehicle information systems, enhance the situational awareness of vehicles and provide motorist/passengers with an information-rich travel environment. Elements (such as personal devices, vehicles, sensor and actuators, infrastructure) contained within the IoV environment can be represented as objects or devices that can interact with each other. This interaction, known as D2D interaction (Bello & Zeadally, 2016), has become an integral part of the IoT and might include multiple types of interactions (Ailisto, Arkko, Evesti & Turunen, 2011). These D2D interactions in the IoV environment may involve many devices (inside and outside of the vehicle) which can communicate with each other, collect, exchange, store and analyse information or make decisions with minimal human interventions.

In our proposed IoV model, we define six types of D2D interactions: (I) V2V, (II) V&P, (III) V&R, (IV) Vehicle and Sensor (V&S), (V) Vehicle and Infrastructure (V&I) and (VI) Roadside and Personal (R&P) device. Additionally, we include two internal interactions (VII) Roadside-to-Roadside (R2R) and (VIII) Sensor & Actuator (S&A) as shown in Figure 1.

3.2. Network model

An IoV network model requires a multi-level collaboration model that considers the different characteristics such as multi-users (drivers, passengers and pedestrians), multi-vehicles (vehicles, motorcycle, bicycles), multi-devices (sensors, actuators, mobile devices, access points), multi-communication models (point to point, multi-point, broadcast, geocast), multi-networks (wireless or wire networks) multiple technologies (WiFi, Bluetooth, Worldwide Interoperability for Microwave (WiMAX), LTE) and multiple characteristics (latency, throughput, packet loss) to integrate personal devices, vehicles, sensor and actuators, technologies and the environment through an intra-vehicular model and an environmental model as shown in Figure 2.

The intra-vehicular model focuses on communications inside the vehicle to support the following interactions: V&P devices, V&S and Sensors and Actuators (S&A).

3.3. Environmental model

The environmental model describes communications outside the vehicle, enabling interactions among multiple vehicles, devices and networks. Both models work together to provide a set of services that improves safety, comfort and reduces traffic congestion using V2V, V&R, V&P devices and R&P device interactions.
3.4. Layered IoV architecture

We propose a seven-layered IoV model architecture that allows a transparent interconnection of all network components and data dissemination in an IoV environment. The IoV model supports: a user-vehicle interface to manage the interactions between the vehicle and the driver, a security layer to manage authentication, authorization and accounting of all the transactions, a communication interface which selects the optimal network to transmit data.
the collected information. For example, if we use a Wi-Fi network, it selects the best service provider after considering the requirements of the communication, the vehicle profile, quality of the network connection, and the transaction costs, to achieve the desired quality of communication. Figure 3 shows our proposed seven-layered architecture.

3.5. User interaction layer

In-vehicle computing systems focus on two types of computing and communications systems (1) information-based systems, and (2) control-based systems. Information-based systems provide relevant information such as route information, traffic conditions, car parking availability and warning/advice regarding risks to components of the driving environment, the vehicle or the driver. Some companies have been focusing their efforts on the development of solutions towards the design and development of IoV. For example, Google and several leading car manufacturers have created the Open Automotive Alliance to develop a common platform based on Android to make the vision of the connected car a reality (OAA, 2016). Apple has developed “CarPlay” for enabling iPhone services inside a vehicle (Apple, 2014). Control-based systems monitor changes in driving habits and experiences that affect the routine, operational elements of the driving task such as adaptive cruise control, speed control, lane keeping and collision avoidance.

Designing user interfaces for in-vehicle systems opens many new challenges. One of the challenges is to design systems that make driving safer while satisfying the users’ needs. Devices may affect driving performance as well as visual attention. The level of workload when using displays and controls becomes a critical safety-related factor. Some efforts have focused on developing new interfaces (Grah, Meschtscherjakov, & Tscheligi, 2016; Meschtscherjakov, Döttling, Rödel, & Tscheligi, 2015; Meschtscherjakov, Wilfinger, Murer, Osswald, & Tscheligi, 2014; Trösterer, Meschtscherjakov, Wilfinger, &
Tscheligi, 2014) which provide functionalities that do not rely on the driver’s vision as is the case with traditional screen-based interfaces. In this context, this architecture layer provides a direct interaction with the driver through a management interface to coordinate all driver notifications and selects the best display element based on the current situation or event to help reduce driver’s distractions. For example, if there is a collision risk with the vehicle ahead, a set of lights on the instrument board or windshield can be activated while a sound is emitted to alert the driver.

### 3.6. Data acquisition layer

Data acquisition aims at gathering data relevant to safety, traffic information, infotainment, from a given area of interest from all the sources (vehicle’s internal sensors, global positioning system, inter-vehicle communication, body sensors, WSN, and different devices such as cellular phones, sensors and actuators, traffic lights and road signals) located on streets and highways. Several data collection schemes based on the division of the roads into groups of contiguous clusters and the use of a cluster-head have been proposed in the literature (Brik, Lagraa, Cherroun, & Lakas, 2013; Chang, Lin, & Chen, 2008; Palazzi, Pezzoni, & Ruiz, 2012). Other efforts have been focusing on dynamically collecting data based on the vehicle’s mobility and network topology changes (He & Zhang, 2014; Soua & Afifi, 2013).

In the last decade, several efforts have been involved in the development and definition of low-power D2D standards and solutions (Andreev et al., 2015; ETSI, 2014; oneM2M, 2014; Sheng et al., 2013), generating many promising radio technologies for D2D connectivity for local and wide area networks.

We classify data transmissions for two types of interactions: intra-vehicular interaction and inter-vehicular interaction. Intra-vehicular mode focuses on the transmission of sensors’ data to a central device inside the vehicle via an in-vehicle wired or wireless network. In IoV, we expect that vehicles will be equipped with about 200 sensors per vehicle by 2020 (Pinelis, 2013). As sensors are stationary, the sensor network topology does not change. Therefore, the sensors inside the vehicle do not suffer from energy constraints because they are connected to the vehicle’s power system and all sensors are required to report the collected information to the central unit which is known as Electrical Control Unit (ECU) to execute different tasks for the control and feedback inside the vehicle. Additionally, data transmission requires low latency, high reliability and a high level of security to protect the vehicle control systems (Zhang, Antunes, & Aggarwal, 2014). The type of intra-vehicle data acquisition network has become a research focus in IoV. Several network technologies (Chao & Yanmin, 2013; Hessain et al., 2010; Hu, Huang, He, Ai, & Chen, 2014; Yuan, Lei, Xue, & Xingshe, 2013) have been studied for efficient, reliable, timely data transmissions inside the vehicle. Other research efforts have evaluated networking technologies in terms of their main features such as transmission time, range, network size and so on (Idris & Muhammad, 2016; Lee, Su, & Shen, 2007). Table 2 summarizes some of the results of these past studies.

Bluetooth supports a data rate up to 3 Mbps. However, this technology requires a high power level for data transmissions and has poor scalability because a maximum of eight devices (Langhammer & Kays, 2012) can be supported. ZigBee is a viable solution for an intra-vehicle network, supporting a data rate of 250 Kbps, but its main problem is the
noise and interference from other devices (de Francisco, Huang, Dolmans, & de Groot, 2009; Tsai et al., 2007). Wi-Fi Halow is a technology developed by IEEE to extend the applicability area of 802.11 networks through the design of an energy efficient protocol that allows thousands of devices to work at the same time. One of the benefits of this technology is its extended range. With this technology, stations and devices are grouped together to minimize contention over the air media, and they use little power due to predefined wake and doze periods (Khorov, Lyakhov, Krotov, & Guschin, 2014). Finally, ultra-wideband is a technology that supports short-range communication at data rates up to 480 Mbps, and has been shown (Qu, Wang, & Yang, 2010; Sadi & Ergen, 2013) to be a viable technology that satisfies the reliability and energy requirements of intra-vehicle systems.

Inter-vehicular interactions include data transmissions external to the vehicle and communication with other external entities such as vehicles, sensors, devices and pedestrians of the IoV ecosystem. All information that is generated by other vehicles and motorcycles, pedestrians’ devices, sensors and communication devices will be shared in real time. This information exchange will enable a variety of safety and infotainment applications via wireless communications.

For V2V, &R and V&I communication, the most predominant access technologies are: (1) IEEE WAVE (Wireless Access in Vehicular Environment) standard which includes the specification of Dedicated Short-Range Communications (DSRC), the IEEE 802.11p for PHY and MAC layers and the IEEE 1609 family for upper layers. Academia has made several efforts (Bharati & Zhuang, 2013; Booysen, Zeadally, & Rooyen, 2011; Omar, Zhuang, & Li, 2012; Wu et al., 2013) to analyse and enhance DSRC performance through various PHY and MAC layer optimizations. DSRC enables vehicles to exchange messages over a range of about 300 m. Dynamic Spectrum Access (DSA) is used as a complementary technology to DSRC. DSA enables vehicular communication over unused spectrum for different communication technologies such as TV spectrum as shown in (Ihara, Kremo, Altintas et al., 2013; Altintas et al., 2011; Altintas et al., 2013; Wang, Song, & Han, 2013). 4G/LTE technology uses the 1700 and 2100 MHz frequency bands, and supports data transfer speed up to 129 Mbps and high mobility through soft handoff and seamless switching. LTE has been proposed as a viable technology for vehicular machine-to-machine communication (Booysen, Gilmore, Zeadally, & Rooyen, 2012) because of its high data rate, low latency and large coverage (Khan, Misic, & Misic, 2016; Piro et al., 2015). WiMAX provides Internet access with a coverage up to 50 km with a data rate of 70 Mbps (Chaqfeh, Lakas, & Jawhar, 2014) and offers broadband access to mobile users. This technology has been used mainly for implementing road safety and traffic analysis applications (Doyle, Jaber, & Tepe, 2013; Hsu, Wang, & Tseng, 2014; Tiwari & Kushwah, 2015).

### Table 2. Comparison of wireless technologies for intra-vehicular communications.

| Parameter                  | Bluetooth | ZigBee | Wi-Fi HaLow | Ultra-wideband |
|----------------------------|-----------|--------|-------------|----------------|
| Frequency                  | 2.4 GHz   | 868 MHz, 915 MHz and 2.4 GHz | 900 MHz | 3.1–10.6 GHz |
| Max. signal rate           | 1,2,3 Mbps| 20–250 kbps | Up to 347 Mbps | 53.3–480 Mbps |
| Coverage                   | 10 m      | 10–100 m | Up to 1 km | 300 m |
| Max. no of cell nodes      | 8         | >65000 | Up to 6000 devices | 8 |
| Nominal TX power           | 0–10 dBm  | (−25) −0 dBm | −17 dB | −41.3 dBm/MHz |
| Security                   | 128-bit AES | AES | | |
| Number of RF channels      | 79        | 1/10; 16 | 26 channels | 1–15 |
| Channel bandwidth          | 1 MHz     | 0.3/0.6 MHz; 2 MHz | 2 MHz and 16 MHz | 500 MHz–7.5 GHz |
3.7. Data filtering and pre-processing layer

In IoV, devices have the potential to generate huge amounts of data although much of it may not be relevant (Contreras-Castillo, Zeadally, & Guerrero-Ibañez, 2016). Data collection, data filtering and data dissemination are important processes to fully enable the IoV (Ahmed et al., 2016). The data filtering and pre-processing layer analyses the collected information and performs some filtering on the data to avoid the dissemination of irrelevant information and reduce the network traffic.

Several data filtering approaches have been proposed in the literature (Fazio, Puliafito, & Villari, 2014; George, Kang, & Shekhar, 2009; Preuveneers & Berbers, 2014). However, more research is needed to develop novel intelligent data mining techniques that can efficiently extract relevant data quickly and accurately.

Regarding vehicles’ information dissemination, some techniques focus on the identification of a small group of vehicles in charge of re-broadcasting the information (Rubin, Baiocchi, Cuomo, & Salvo, 2013), others use direct and indirect packet relay through the store-carry-forward mechanism (Viriyasitavat, Bai, & Tonguz, 2010).

Dissemination protocols do not generally distinguish relevant information based on the environment and application type or service. Consequently, as different devices in IoV do not know which information will be relevant, they will disseminate all information, causing network bandwidth saturation. If real-time data collection is needed, storing or sending aggregate data bursts is not required. By adding intelligence to devices in the IoV in order to filter data before it is disseminated could significantly reduce network bandwidth consumed.

Dissemination decisions might be created for the different devices in IoV based on service profiles and subscribed (or active) services.

3.8. Communication layer

In the IoV environment, multiple wireless networking technologies will be available, creating a heterogeneous communication environment (Kellokoski, Koskinen, & Hämäläinen, 2014). Each network has its own characteristics, but all networks will need to be integrated in a way such that the environment provides full connectivity and seamless services along with the optimal quality to the users (Kumar, Mallik, & Schober, 2014) based on different parameters such as device location, available access technologies for the user’s device and service requirements.

Solutions for selecting the best access network have traditionally been based on the evaluation of a single attribute such as Received Signal Strength or Signal to Interference Noise (Chang, Chen, & Hsieh, 2009; Kunarak & Seleesathira, 2010). Other works have focused on the Multi-Radio Access Selection Load Balancing where the user selects the network based on the requirements of the service and the network conditions (Guerrero-Ibañez, Contreras-Castillo, Barba, & Reyes, 2011).

In our proposed layered design architecture, the communication layer selects the best network to send the information based on several selection parameters such as congestion and QoS level over the different available networks, information relevance, privacy and security among others. The challenge in this layer is the design of an intelligent approach that selects the most suitable network using the relevant information and
measurements. IoV is associated with several criteria when it comes to the network selection and needs to use Multiple Attributes Decision Making (MADM) algorithms, such as SAW, TOPSIS, MEW, GRA, VIKOR, etc. (Ahuja, Singh, & Khanna, 2014; Martinez-Morales, Rico, & Steven, 2010) to select the most suitable network in terms of the Quality of Service for the type of applications and services that will be developed for the IoV environment. Other proposed algorithms have been based on fuzzy algorithms to determine the values of attributes that select the best network (Miranda Rios, Lira Gondim, & Castro Monteiro, 2012; Zhang, Zhang, Lv, & He, 2013). The key of the MADM algorithm is to determine the impact of each attribute after considering different aspects such as the quality of the connections, the preferences of the end users and the cost as discussed in Guerrero-Ibáñez et al. (2011) and Kosmides, Rouskas, and Anagnostou (2014).

3.9. Control and management layer

This layer is a global coordinator that is responsible for managing the different network service providers that are within the IoV environment. Its function is to manage the data exchange among the various services. In this layer, different policies (such as traffic management, traffic engineering, packet inspection) and functions that can be applied to better manage the information generated by all devices such as sensors inside and around vehicles, roadside infrastructure and user devices in the environment.

3.10. Business layer

This layer processes large amounts of information using various types of cloud computing infrastructures locally and remotely. Some of the functions of the layer include storing, processing and analysing all the information received from the other layers, making decisions based on data statistical analysis and identifying strategies that help in applying business models based on the usage of data in applications and the statistical analysis. Tools such as graphs, flowchart and critical analysis are used for the statistical analysis. The results of the processed information can be used by different data services providers to further improve the service or to develop new applications. The results obtained after processing can also be used by various government agencies in the development of future infrastructures, Vehicle-to-Business services (Contreras-Castillo et al., 2016) and policies to help improve or better manage road traffic.

3.11. Security layer

Security is critical and must be considered at device, network and application levels. This layer communicates directly with the rest of the layers. It implements all security functions (such as data authentication, integrity, non-repudiation and confidentiality, access control, availability, among others) within the proposed architecture to exchange data among sensors, actuators, user’s devices through secure networks and service providers. The layer is designed to mitigate various types of security attacks (such as cyberattacks and others) in IoV.
4. Protocol stack

In this section, we present a two-plane (operational and security) protocol stack in which we support current protocols in the different layers of our proposed architecture (as shown in Figure 4). The protocol stack is based on different projects for vehicular networks which includes WAVE (Transportation, 2016), C2C (RITA, 2011) and CALM (Castermans, 2013) and projects for IoT including HyDRA (The Hydra Project, 2011), IoT6 (IoT6.eu, 2014) and IoT-A (Bui, 2014).

The operational plane describes the protocols used in six layers of our architecture. The user interaction layer contains the different ways to interact with the driver and passengers. These ways include haptic, sound and visual. In the acquisition layer, access protocols are classified into two transmission categories: intra-vehicular and environmental. Intra-vehicular considers the communication inside the vehicle and includes protocols such as Bluetooth, Radio Frequency Identification, Near Field Communication, IEEE 1609 WAVE, WiFi HaLow and ultra-wideband. Environmental includes all protocols for communication networks used outside of the vehicle which include IEEE 802.15.4, 802.11p, 2G/3G/4G/ LTE, WiMAX and Low-Power Wide Area Network. The pre-processing layer defines the syntax and formats for data exchange among the nodes in the IoV ecosystem, including protocols such as Extensible Messaging and Presence Protocol, Constrained Application Protocol and Lightweight Local Automation Protocol among others. The communication layer includes routing protocols and transportation layers that complement the current set of IP and TCP/UDP protocols and defines a Global Handoff Management that allows seamless switching among the different access technologies and

![Figure 4. Protocol stack for IoV.](Image)
complementary protocols such as 6LowWPAN, Routing Protocol for Low-Power and Lossy Networks, Micro Internet Protocol Routing Over Low-Power and Lossy Networks that have been proposed in several IoT projects mentioned previously. The management layer includes protocols for service management such as CALM Service layer (CALM-SL) and WAVE-1609.6 service, the TR-069 protocol and the Open Mobile Alliance for Device Management (OMA-DM), that complement business layer protocols such as Vehicular Cloud Computing, Big Data Analysis (BDA) and different smart business-oriented models for insurance, sale, service and advertisement (Kaiwartya et al., 2016).

The security plane spans over the remaining six layers of our architecture and its main goal is to support all security functions in the IoV ecosystem. One of the open challenges in IoV is the definition of security protocols. The security information connector proposed in WAVE project, Security Management Information Base developed under C2C project and the Hardware Security Module proposed in the CALM project are some example of the efforts to support future security enhancements to IoV. Other efforts have been focused on the issue of efficient security signature verification for IoV applications (Banani & Goron, 2014; Hamida & Javed, 2016).

5. IoV case study

In this case study, the IoV architecture is divided into five different components as shown in Figure 5. The first is the vehicle. The second consists of nearby IoV elements (environmental devices), the third and fourth ones are the network and roadside infrastructures for IoV components respectively and the last one comprises of the cloud elements. Let us assume there is a mechanical problem with a member vehicle in the IoV ecosystem: (1) Several car sensors (forming part of the acquisition layer) collecting data about the performance of the vehicle detect the problem inside the vehicle. The ECU is immediately notified of the problem using a standard protocol (Bluetooth, Ethernet or other) with

![Figure 5. Sequence diagram for an IoV scenario.](image-url)
information related to the event and an alert signal is triggered. (2) The driver is notified through one or more of the user interfaces (user interaction layer). (3) The ECU performs a quick filtering of the information (pre-processing layer) into two categories: one for the mechanical service and another for the environment. (4) First, it selects the best access technology for data dissemination to start broadcasting a message at periodic intervals to the nearby devices (external to the car). (5) The data being disseminated include the disabled vehicle’s position and if it is blocking the road (pre-processing layer). (6) The receiving cars notify the drivers through one or more interface (user interaction layer) such as visual, audio or haptic, and if needed, provide alternative routes using the cars’ GPS and reduces its speed to avoid frontal collisions. (7) After a car receives the message, it also notifies the roadside infrastructure to start displaying messages for other vehicles in the IoV ecosystem (management layer) and along with the sensing information, the roadside infrastructure makes informed decisions (e.g. by opening an alternate car lane, changing traffic lights, deployment and display of alternative routes for stopped cars that will improve the overall traffic flow. (8) The roadside infrastructure stores information to the cloud for future statistical analysis.

(9) The vehicle initiates a status analysis (pre-processing layer) to be sent to the vehicle’s manufacturer to evaluate the internal damage and determine if it is necessary to isolate it to avoid further damage (such as a short circuit or an explosion) inside the vehicle. (10) The selector module performs an evaluation of the available technologies within the environment (communication layer) and selects the most appropriate network connection based on different elements (vehicle profile, occupants’ profiles and evaluation during the event, security, coverage, information volume and costs among others). (11) All the information is encrypted and transmitted through a secure connection (security layer) because it includes internal information about the vehicle, and possibly other types of information (stress and anxiety levels, physical status, or physiological, using WSNs or Body area networks) about the car’s driver or occupants. (12) All the status information sent out from the car is stored in the cloud to keep a detailed personalized report (business layer). The results from such a report can be used in a follow-up study (using data mining or BDA) of the factors that caused the failure to determine how to avoid similar failures in other vehicles of the same model in the future or to further improve the design in new models thus reducing the costs of repairs or recalls of damaged cars.

Finally, the company notifies the driver about the type, level and response time for help to arrive, in the form of a towing car, a specialized mechanic to repair the damage (depending on the damage level) or with a replacement car to transport the occupants (business layer – client support).

6. Conclusion

IoV is transforming the transportation system into a worldwide heterogeneous vehicular network. IoV provides numerous benefits including dynamic information services, intelligent vehicle control and applications to reduce insurance rates and increased productivity due to reduced traffic congestions and car accidents. In this paper, we have presented a seven-layered architecture for IoV. First, we identified the main elements that make up the IoV ecosystem described their roles and proposed an interaction model among the main elements. Second, we introduced a network model consisting of the intra-vehicular model
and the environmental model. We describe a protocol stack that integrates existing protocols into the IoV ecosystem and supports the standards used for all participants’ interoperability. Finally, we presented a case study and a sequence diagram that shows how the proposed seven-layered architecture could be applied to a real-life scenario of IoV.

We argued that the proposed architecture will benefit the readers in terms of understanding the interaction model, network model and layered architecture. IoV will promote the integration of automotive and information technology which will contribute to the development of applications related to energy efficiency, connected devices, security and safety all of which will ultimately help reduce the lack of coordination and communication among vehicles and improve products, services and experiences.

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No potential conflict of interest was reported by the author.

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