Internet of Vehicles: Motivation, Layered Architecture, Network Model, Challenges, and Future Aspects

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Abstract*—Internet of Things (IoT) is smartly changing various existing research areas into new themes including smart-health, smart-home, smart-industry and smart-transport. Relying on the basis of 'Smart-Transport', Internet of Vehicles (IoV) is evolving as a new theme of research and development from Vehicular Adhoc Networks (VANETs). This paper presents a comprehensive framework of IoV with emphasis on layered architecture, protocol stack, network model, challenges and future aspects. Specifically, following the background on evolution of VANETs and motivation on IoV, an overview of IoV is presented as a heterogeneous vehicular networks. The IoV includes five types of vehicular communications; namely, Vehicle-to-Vehicle, Vehicle-to-Roadside, Vehicle-to-Infrastructure of cellular networks, Vehicle-to-Personal devices and Vehicle-to-Sensors. A five layered architecture of IoV is proposed considering functionalities and representations of each layer. A protocol stack for the layered architecture is structured considering management, operational and security planes. A network model of IoV is proposed based on the three network elements including cloud, connection and client. The benefits of the design and development of IoV are highlighted by performing a qualitative comparison between IoV and VANETs. Finally, the challenges ahead for realizing IoV are discussed and future aspects of IoV are envisioned.

***Index Terms*—Vehicular adhoc networks, Internet of vehicles, Cloud computing, heterogeneous networks.**

I. INTRODUCTION

THE concept of a universal network framework including all the existing heterogeneous networks is being strongly experienced and shaped due to the highly growing number of things; e.g., vehicles on road, smartphones on the hands of people, laptops and tablets in offices, TVs and music systems in homes and other sensor enabled devise in our daily life. This global network of things is nothing but a future Internet which is being shaped as Internet of Things (IoT) among researchers and practitioners in academia and industries [1].

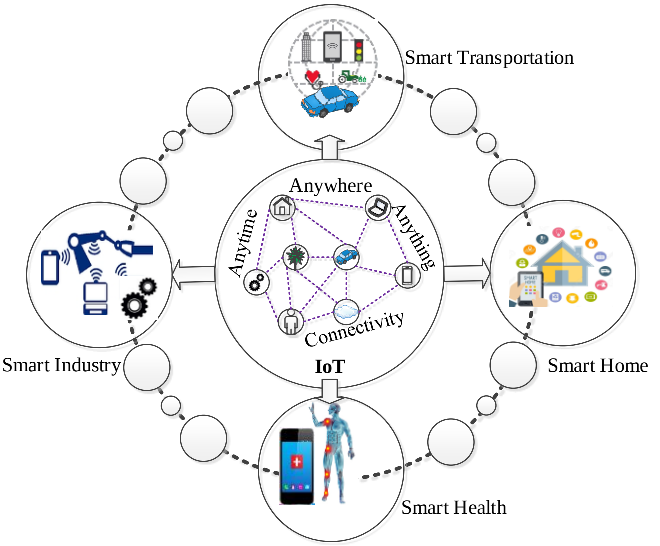

Fig. 1. The smart impact of IoT on different research and development areas

In IoT, intelligent interfaces are utilized for seamlessly integration of heterogeneous networks. Interoperability among heterogeneous devices is one of the major goals of IoT [2]. IoT is revolutionizing many new research and development areas. IoT is integrating smartness into the existing areas; e.g., smart-health, smart-home, smart-energy, smart industry and smart transport (see Fig. 1) [3]. Internet of Vehicle (IoV) is one of the revolutions mobilized by IoT. IoV is evolving from Vehicular Adhoc Networks (VANETs) to achieve the vision of 'from smartphone to smartcar' [4]. The sole aim of conventional VANETs was to enhance traffic safety and efficiency using real time communication among advanced wireless access technology enabled vehicles with or without the help of Road Side Units (RSUs).

In spite of having huge potential to address safety and efficiency issues of traffic with lower operational cost, VANETs has not been able to attract commercial interest [5]. The commercialization problem of VANETs includes the issues related to pure adhoc network architecture [6], unreliable Internet service [7], incompatibility with personal devises [8], unavailability of cloud computing [9], lower accuracy of the services, and cooperative operational dependency of the network. Moreover, inspite of the continuous modernization of vehicles and road infrastructure considering safety as a prime goal, the growing traffic casualties throughout the world is a serious cause of concerns. The reliable vehicular communications would play a significant role in reducing traffic casualties [10]. A huge growth in number of on-road vehicles has been predicted by renowned organizations [11]. The growth would open a

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significantly challenging but profitable market for ‘connected vehicles’ [12].

In this context, this paper presents a comprehensive framework of IoV with emphasis on layered architecture, network model, challenges and future aspects. The framework has significant potential to provide reliable vehicular communications. The IoV could effectively reduce traffic casualties and attract commercial interest in vehicular communications. The key contributions of this paper are as follows.

- A five layered architecture of IoV is proposed considering functionalities and representations of the layers. A protocol stack for the layered architecture is structured considering management, operational and security planes.
- A network model is proposed by identifying three network elements of IoV including cloud, connection and client. The role of cloud computing, heterogeneous network connection and potential client applications in IoV are explored.
- The benefits of realizing IoV are highlighted by performing a qualitative comparison between IoV and VANETs.
- The challenges and issues ahead in the design and development of IoV are discussed. The future aspects of IoV are envisioned.

The rest of the paper is organized into following sections. Section 2 provides background, motivation and overview of IoV. Section 3 proposes a five layered architecture and protocol stack of IoV. Section 4 proposes a network model of IoV based on the three network elements; namely, cloud, connection and client. Section 5 highlights the benefits of IoV over VANETs. Section 6 discusses the challenges and issues ahead in the design and development of IoV. The future aspects of IoV are envisioned in section 7. Section 8 concludes the framework of IoV.

II. BACKGROUND, MOTIVATION AND OVERVIEW

In this section, conventional VANETs is introduced. The motivation for the design and development of IoV is presented. An overview of IoV is provided as a heterogeneous vehicular networks.

A. *Conventional VANETs*

Due to the significant research and technology advancements in wireless communication, the traditional Intelligent Transport System (ITS) has evolved towards vehicular communication. The concept of Vehicle-to-Vehicle (V2V) and Vehicle-to-Roadside unit (V2R) communication came into existence in research and developments as another communication network known as Vehicular Adhoc Networks (VANETs) [13]. It enables communication among on-road vehicles with and without the help of any pre-established infrastructure alongside roads or moving on roads. A number of state-of-the-art equipment related to new generation Wireless Access Technology (WAT) are incorporated with vehicles. The equipment include display screen, sensor, antenna, camera, radar, Global Positioning System (GPS) receiver, multiple Application Units (AU), Central Processing Unit (CPU), etc. The incorporation as on-board units of vehicles enables vehicular communication for enhancing safety, comfort and affordability. In sparse vehicular network environment, pre-established infrastructure or pre-specified regular vehicles of a particular route such as buses are used as Road Side Units (RSUs) for providing communication among on-road vehicles [14].

The communication architecture of VANETs can be divided into three categories including Wireless Access in Vehicular Environments (WAVE) based Wi-Fi, adhoc and hybrid (see Fig. 2). In WAVE based Wi-Fi-driven architecture, RSUs alongside roads are used as wireless access points which provide communication coverage to the vehicles inside its coverage area. In adhoc architecture, group of on-road vehicles form adhoc networks using WAVE. These networks perform operations independently without any infrastructure support. In hybrid architecture, cellular and adhoc architectures both using WAVE perform their operations in collaborations [15].

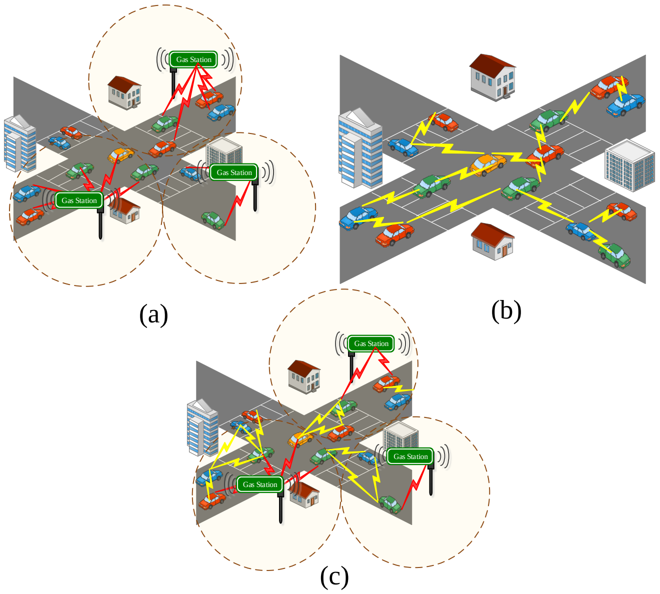


Fig. 2. The communication architectures of VANETs: (a) WAVE base Wi-Fi; (b) Adhoc; (c) Hybrid

While conceptualizing VANETs two major objectives were identified. Firstly, to improve traffic safety and secondly, to enhance traffic efficiency in terms of reducing time, cost and pollutant emission. Due to the commercialization related issues in VANETs, most of the countries of the world are lacking of the real implementation of VANETs. Some of the developed countries including US and Japan are using basic implementation of VANETs. This leads to the design and development of more reliable and market oriented architecture for vehicular communication [10].

B. *Motivations*

The motivation for the design and development of IoV is divided into three folds. Firstly, the commercialization related issues of VANETs are pointed out. Secondly, the volume of growing traffic casualties is examined. Thirdly, the huge market opportunity ahead for IoV is assessed.

1) *The Commercialization Issues in VANETs*

In spite of having huge potential in VANETs to address safety and efficiency issues of traffic with lower operational cost, it has not been able to attract commercial interest of industries in the last two decades [5]. Some of the reasons of lesser commercial interest in VANETs are pointed out below.

- The framework of VANETs could not guarantee the global and sustainable services by ITS applications. This is due to the pure adhoc network architecture. Once a vehicle becomes disconnected from an adhoc network, it loses the services from the network inspite of the vehicle being on-road. This is due to the inability to collaborate with other alternative reachable networks [6].
- In the current framework of VANETs, Internet connectivity could not be guaranteed. Therefore, commercial applications are not available to drivers and passengers. This is due to the dependency of commercial applications on reliable Internet connectivity [7].
- Inspite of the considerable growth of personal devices in our daily life, the devices are not able to communicate with VANETs. This is due to the incompatible network architecture [8].
- Intelligent decisions based on the big data mining driven computations are not possible in current VANETs architecture. This is due to the computing and storage constraints and unavailability of cloud computing services at vehicles [9].
- Accuracy of the services in ITS applications is significantly lower, considering the risk involved in relying on the services for better driving experiences. This is due to the computation based on local knowledge of traffic environments in VANETs.
- Operations of the vehicular network are highly depended on the cooperation of network users. The dependency diminishes the reliability of the services of VANETs [15].

2) *The Growing Traffic Casualties*

The three major issues related to on-road traffic include safety, efficiency and pollution. These are leading causes of concern on the design and development of IoV. IoV would provide more reliable framework for vehicular communications, as compared to VANETs for smart ITS applications. Reliable vehicular communications would effectively reduce traffic casualties [10]. The growing traffic causalities throughout the world have been reported in various surveys [16, 17]. Major facts of some of the reports are pointed out below.

According to a report of the World Health Organization (WHO), the total number of worldwide road traffic deaths due to the various traffic accidents on road is 1.25 million per year [16]. The average number of deaths per day is nearly 32876. Considering only young people (15≤age≤29), road traffic injuries has caused the highest number of deaths in 2012 among the top ten reasons of causalities. According to another report, road crashes are resulting in huge economic cost; i.e., 3% of the world's GDP globally [17]. The huge growth of vehicles on-road is resulting as one of the major causes of air pollution specifically in capital cities. The reports suggest that there is an emergent need to reduce traffic casualties on road using more reliable vehicular communication based safety applications.

3) *Market Opportunities*

The IoV offers huge market opportunity not only for automobile industry, but also for a range of other industries including IT equipment manufacture, software industry and Internet service providers. The number of on-road vehicles has been predicted to increase significantly in the world [18]. Due to the higher motorization rate, congestion would result in longer on-road travelling time in coming years. Even if 5 minutes of the time wasted in travelling globally is monetized then it is expected to generate Euro 25 billion revenue per year by 2030 [19]. Automobile industry is expected to increase the profit margin of Euro 54 billion in 2012 to Euro 79 billion by 2020 [11]. The effective utilization of travelling time is also one of the key objectives of IoV. Another key driver for the design and development of IoV is the recent advancements and higher market penetration rate of IoT [20]. In the growth of IoT, automobile industry is one of the fastest growing industries [21]. The connected car sale would reach up to 81 million annually and 80% sale of the new cars would have some form of connected drive technology by 2025 (see Fig. 3) [12]. The potential economic value produced by IoV is estimated to be in the range $210-740 billion per year by 2025 [22].

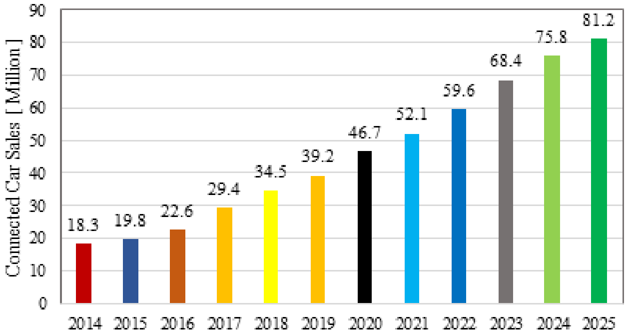


Fig. 3. The prediction of car sales with some form of connectivity till 2025

C. *Overview of IoV*

Although IoV is a new concept and would emerge as an established research and development area in near future yet, the usage of concept has already been started as initial stage in many countries. In US, security chip is being installed in each online devices including vehicles to define identity for every entities in Internet [23]. In Delhi, all registered autos, electronic vehicles, government buses and metro rails are equipped with GPS and Wireless Fidelity (Wi-Fi) [24]. European Commission has taken number of initiatives for development of next generation Cooperative Intelligent Transportation Systems (C-ITS) [25]. Various reports suggest that there is a positive thinking about the 'Connected Vehicles' in counties including US, UK and Australia [26]. Google is working with leading automobile and IT companies for developing Android system for 'connected drive' under the consortium Open Automobile Alliance (OAA) [27]. Apple has developed a system 'CarPlay' which enables driver to use all the services of iPhone through the display of car with voice support feature [28]. All the aforementioned efforts are the steps towards the design and development of IoV.

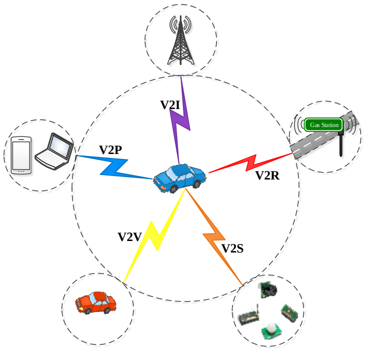


Fig. 4. The five types of vehicular communications of IoV

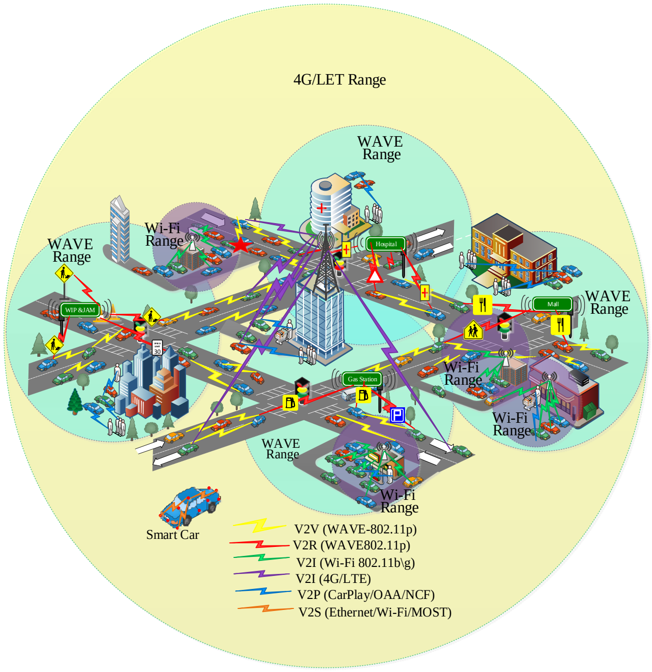


Fig. 5. The realization of IoV with heterogeneous vehicular networks

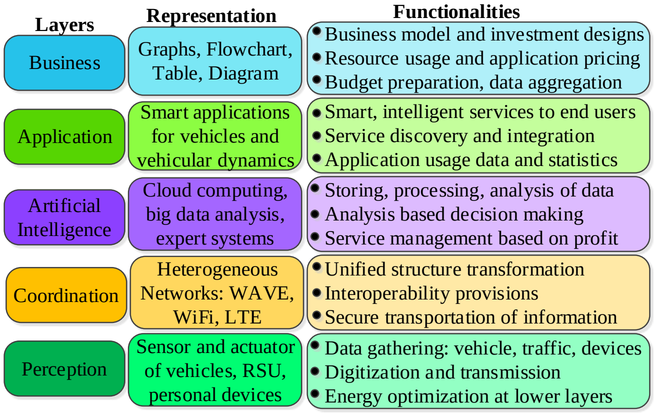
A global network of WAT enabled vehicles involving Internet and other heterogeneous networks is proposed as Internet of Vehicles (IoV). The heterogeneous network architecture of IoV includes five types of vehicular communications. The types include Vehicle-to-Vehicle (V2V), Vehicle-to-Roadside unit (V2R), Vehicle-to-Infrastructure (V2I) of mobile networks, Vehicle-to-Personal devices (V2P) and Vehicle-to-Sensors (V2S) (see Fig. 4). Each vehicular communication of IoV is enabled using a different WAT. The WAT include IEEE WAVE for V2V and V2R, Wi-Fi and 4G/LTE for V2I, CarPaly/NCF for V2P and MOST/Wi-Fi for V2S. The communication architecture not only includes vehicles and RSUs, but also other communication devices. The inclusion of a range of devices makes the architecture more complex but market oriented as compared to VANETs. The heterogeneous vehicular network framework of IoV has significant potential to guide and supervise vehicles. It has the ability to provide reliable communication platform for abundant mobile Internet and multimedia related applications. An example of the framework is presented in Fig. 5 with heterogeneous network coordination and related services. The realization of heterogeneous vehicular network architecture is a challenging task [29]. IoV is explored in detail in following sections focusing on layered architecture, network model, benefits, challenges, and future aspects.

III. LAYERED ARCHITECTURE AND PROTOCOL STACK

The layered architecture design of a universal network which includes heterogeneous networks is a quite challenging task. It requires to identify and effectively group similar functionalities and representative elements of heterogeneous networks as a layer. Optimizing the number of layers and enhancing the differentiability among layers are the significant priorities of the layered architecture design. Along with the layering of functionalities and representative elements, various network characteristics of the heterogeneous architecture are considered. The network characteristics include interoperability, scalability, reliability, modularity. The architecture of IoV should be able to interconnect vehicles to heterogeneous networks and devices. Therefore, an open and flexible layered architecture in terms of technology adaptation is more suitable for the architecture. Some of the key objectives of the architecture design of IoV include strong integration with Internet, Service Oriented Architecture (SOA) and plug-and-play based interface. Due to the fact that the investigations in IoV is on early stage, mostly in industries and research projects [27, 28, 30], from the best of our knowledge, this is the first effort towards the layered architectural design of IoV.

A. Layered Architecture

A five layered architecture is designed including perception, coordination, Artificial Intelligence (AI), application and business layers. The representations and functionalities of each layer are described below in detail and a summarized view is shown in Fig. 6.



Layers	Representation	Functionalities
Business	Graphs, Flowchart, Table, Diagram	• Business model and investment designs • Resource usage and application pricing • Budget preparation, data aggregation
Application	Smart applications for vehicles and vehicular dynamics	• Smart, intelligent services to end users • Service discovery and integration • Application usage data and statistics
Artificial Intelligence	Cloud computing, big data analysis, expert systems	• Storing, processing, analysis of data • Analysis based decision making • Service management based on profit
Coordination	Heterogeneous Networks: WAVE, WiFi, LTE	• Unified structure transformation • Interoperability provisions • Secure transportation of information
Perception	Sensor and actuator of vehicles, RSU, personal devices	• Data gathering: vehicle, traffic, devices • Digitization and transmission • Energy optimization at lower layers

Fig. 6. The five layered architecture of IoV

1) Perception Layer

The first layer of the architecture is represented by the different types of sensors and actuators attached to vehicles,

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RSUs, smartphones and other personal devices which are considered in the framework. The primary responsibility of the layer is to gather information regarding vehicle, traffic environment and devices. The vast of information includes speed, direction, acceleration, position, engine condition and travel documents related to vehicle, on-road vehicle density and weather conditions related to traffic environment, and multimedia and infotainment records related to people. The layer is also responsible for the electromagnetic transformation and secure transmission of perceived data to the coordination layer. The major issues of the layer are the collection and differentiation of captured information in efficient manner in terms of cost and energy.

2) *Co-ordination Layer*

The second layer of the architecture is represented by a virtual universal network coordination module for heterogeneous networks involving WAVE, Wi-Fi, 4G/LTE and satellite networks, through which the perceived information from the lower layer is securely transferred to the artificial intelligence layer for processing. Due to the lack of standards, interoperability and cooperation among different types of networks is one of the main concerns in IoV for providing reliable network connectivity handled by this layer. The prime responsibility of this layer is to process the different structure of information received from heterogeneous networks and reassemble into unified structure which can be identified and processed in each candidate networks.

3) *Artificial Intelligence Layer*

The third layer of the architecture is represented by the virtual cloud infrastructure. It is the brain of IoV and responsible for storing, processing and analysing the information received from lower layer and decision making based on the critical analysis. It works as information management centre where computing and analysis techniques including Vehicular Cloud Computing (VCC) and Big Data Analysis (BDA) and Expert System are major operational components. Due to the number of services offered in cloud environment, service management is also one of the major concern in IoV where exclusive and dedicated services are the requirement of smart applications which are also handled by this layer.

4) *Application Layer*

The forth layer of the architecture is represented by smart applications, ranging from traffic safety and efficiency to multimedia based infotainment and web based utility applications. The layer is responsible to provide smart services to end users which are based on intelligent and critical analysis of processed information by the AI layer. Application layer was also envisioned in VANETs architecture where safety and efficiency applications were main focus and smart applications for commercial purpose were not intended. Efficient discovery of services provided by AI layer for combining as smart applications for end users is one of the major responsibilities of this layer. It also provides end user application usage data to the business layer. Due to the realization of number of smart applications, the framework of IoV is being evolved as global network for reliable vehicular communication. Therefore, these smart applications of the layer are the driving force for the efforts being made in research and developments in IoV.

5) *Business Layer*

The fifth layer of the architecture is represented by the operational management module of IoV. The major responsibility of the layer is to foresight strategies for the development of business models based on the application usage data and statistical analysis of the data. Different types of analysis tools including graphs, flowchart, comparison tables, use case diagram, etc., are the major part of the layer. The other responsibilities of the layer include decision making related to economic investment and usage of resources, pricing of usage of applications, overall budget preparation for operation and management and aggregate data management.

B. *Protocol Stack*

A protocol stack is designed by efficiently organizing the appropriate existing protocols at dedicated one of the five layers (see Fig. 7). The protocol stack aims to accomplish the functional requirements of each layer identified in the architecture. Various protocols are utilized suggested in the projects related to VANETs including WAVE [31], C2C [32], CALM [33] and the projects related to IoT including projects including IoT-A [34], IoT6 [35], HyDRA [36]. The protocol stack has three planes including security, operation and management. The appropriate protocols are identified for different layers and planes of the architecture of IoV by quite efficiently managing the most of the functional requirements using existing protocols.

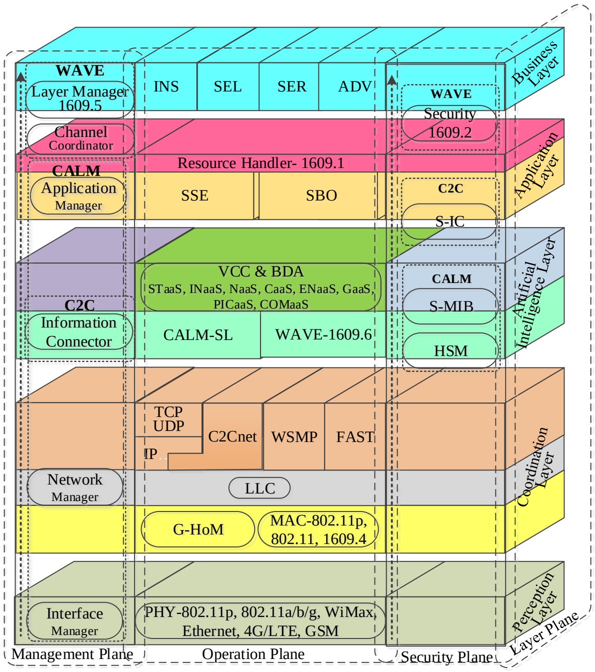

Fig. 7. The protocol stack for the five layered architecture of IoV

1) *Security Plane*

In this plane, security protocols including IEEE 1609.2, Security Information Connector (S-IC), Security Management Information Base (S-MIB) and Hardware Security Module

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(HSM) could be utilized which have been developed under WAVE, C2C and CALM projects; respectively. Security protocols for IoV is still an open research challenge due to the unavailability of clear definitions of layer wise security protocols which is being explored in some recent projects of IoT [37].

2) *Operation Plane*

In perception layer, a number of wireless access protocols could be considered in physical layer including 802.11p [38] of WAVE, 802.11a/b/g of Wireless Local Area Network (WLAN) [39], Worldwide Interoperability for Microwave (WiMax) [40], Ethernet, 4G/Long Term Evolution (LTE) [41], Global System for Mobile communication (GSM) and satellite communications [42]. The coordination layer is divided into three sub-layers including lower, middle and upper. The different MAC protocols could be utilized at lower sub-layer including IEEE 802.11p, 802.11 (a/b/g/n) and 1609.4 along with a Global Handoff Manager (GHM). The design of GHM is an open research challenge in IoV considering the range of technologies considered at perception layer. A Logical Link Control (LLC) protocol could be considered at middle sub-layer. At upper sub-layers, three protocols including C2C network protocol (C2C-net), Short Message Protocol (WSMP) and Fast Application and Communication Enabler (FAST) could be considered for carrying out the operations of network and transport layers apart from traditional IP and UDP/TCP combinations. These protocols are suggested in C2C, WAVE and CALM projects as network layer protocols. The WSMP and FAST do not utilize IP whereas C2C-net uses IP6 for some operations.

In Artificial Intelligence (AI) layer, CALM Service Layer (CALM-SL) and WAVE-1609.6 service related protocols could be considered at the lower sub-layer, Vehicular Cloud Computing (VCC) and Big Data Analysis (BDA) related protocols could be utilized at upper sub-layer including the cloud services Storage as a Service (STaaS), Infrastructure as a Service (INaaS), Network as a Service (NaaS), Cooperation as a Service (CaaS), Entertainment as a Service (ENaaS), Gateway as a Service (GaaS), Picture as a Service (PICaaS) and Computing as a Service (COMaaS). The protocols for AI layer are open research challenges in IoV due to the unavailability of suitable protocols for VCC and BDA. None of the projects related to VANETs have clear definitions of the upper sub-layer but some projects on IoT are working towards these protocols [43, 44]. Application layer includes two sets of applications; namely, Smart Safety and Efficiency (SSE) and Smart Business Oriented (SBO). On the top of these applications, one resource handler protocol 1609.1 defined in WAVE could be utilized for managing resources among smart applications. In business layer, four types of business models including Insurance (INS), Sale (SAL), Service (SER) and Advertisement (ADV) are considered. The business models for this layer is an open research challenge in IoV [45]. The success of IoV also highly depends on the effective and efficient development of these business models which are the most significant for the commercialization of IoV in the related industries.

3) *Management Plane*

In this plane, three protocol groups belonging to the management operations in WAVE, CALM and C2C could be considered. Layer manager IEEE 1609.5 and channel coordinator protocols are developed in WAVE. CALM has suggested three protocols for management purpose; namely, application, network and interface managers. Information connector protocol has been suggested in C2C for the same purpose.

IV. NETWORK MODEL

In this section, a network model of IoV is proposed by identifying major network elements. The building blocks of IoV in terms of network elements more effectively express the meaning and functionalities of IoV as a comprehensive heterogeneous network. The three major network elements of IoV are identified which include cloud, connection and client (see Fig. 8). A logical view of the proposed network model of IoV is shown in Fig. 9 with internal components of each element.

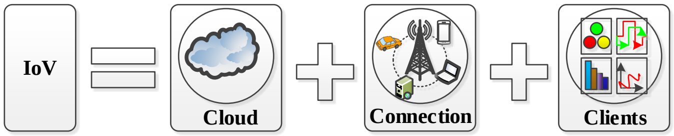

Fig. 8. The three network elements of IoV

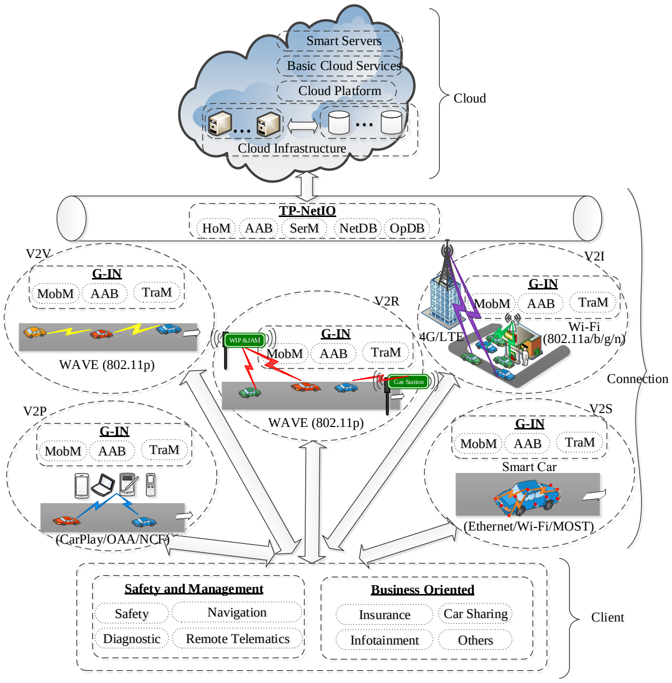

Fig. 9. The network model of IoV with the three network elements

The first element of IoV is the ‘cloud’ which represents the brain of IoV. A range of services related to intelligent computing and processing are offered as primary cloud services. The services are offered on cloud platform provided by cloud infrastructure. The cloud based intelligent computing and processing services are accessed using a reliable ‘connection’ which is the second element of IoV. A range of

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wireless access technologies can be utilized to establish a connection. The different types of vehicular communications of IoV represent a different connection due to the usage of different wireless access technologies. The different types of connections are utilized by smart 'client' applications which is the third element of IoV. Each client application has service requirements which might be different from other clients. The service requirements of a client are defined in terms of characteristics of a wireless access technology. Therefore, a prioritized preference of wireless access technologies are used by client applications. These elements and their roles in IoV are described in detail in following sub-sections.

A. The Cloud

The magnitude of traffic related information would enlarge drastically with the realization of IoV. This is due to the integration of different types of networks with vehicular network. A smart ITS of a city for dynamically collecting, processing and disseminating real time traffic information would require information processing system of petabyte scale [46]. For handling information of this magnitude, cloud computing framework is the best environment. A framework is proposed to highlight the role of cloud computing as an element in IoV by utilizing the concept of cloud based application servers (see Fig. 10). The framework has three major operation levels including basic cloud services, smart application servers and information consumers and producers. The operation levels are based on cloud where traffic information is uploaded, processed, stored and disseminated using cloud architecture. Basic cloud services are the core operation framework for realizing cloud based smart ITS application servers in IoV. The three operation levels are introduced below in terms of major components and their responsibilities.

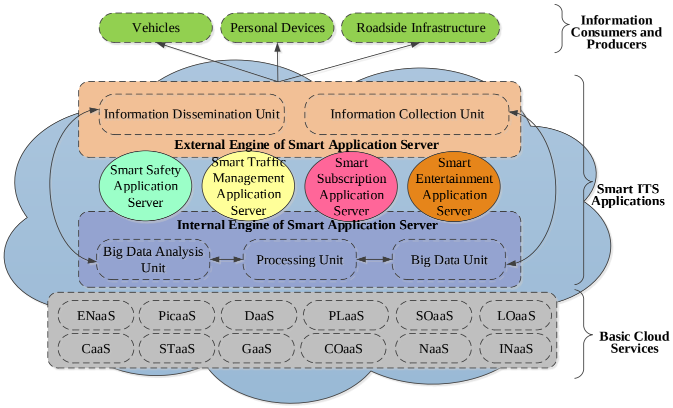

Fig. 10. The role of cloud computing as three operation levels

1) Basic Cloud Services

The basic cloud services include the services offered to smart traffic application servers including Co-operation as a Service (CaaS), Storage as a Service (STaaS), Gateway as a Service (GaaS), Computing as a Service (COaaS), Network as a Service (NaaS), Data as a Service (DaaS). Smart ITS application servers are considered to be developed and deployed on a cloud platform which provides basic cloud services to the applications for IoV [47].

2) Smart ITS Application Servers

Smart application servers of IoV are divided into four categories including traffic safety, traffic management, service subscription and entertainment [48]. Two processing engines; namely, internal and external engines are considered for smart servers. The internal engine includes big data unit, processing unit for big data and analysis unit of processed big data. All the operations of these three units are performed using the basic cloud services offered at cloud platform. The external engine includes information dissemination unit responsible for end-to-end delivery of services to client applications and information collection unit responsible for in-source data gathering.

3) Information Consumer and Producer

The smart devices of IoV including vehicles, personal devices and RSUs are the end user of the intelligent information provided by smart servers. The devices are responsible for data gathering from vehicular traffic environments. The development of business models for organizations related to insurance, automobile production and repair, and other Internet based services is also one of the major usages of the data gathered by smart devices [49].

The aforementioned role of cloud computing makes the 'cloud' one of the important elements in the design and development of IoV. The services offered by the four smart application servers including smart safety, Smart Traffic Management, Smart Entertainment and Smart Subscription are the basis of smartness in IoV [50]. The primary responsibility of the cloud servers is to process and apply artificial intelligence in real time big traffic data to make intelligent decisions for smart client applications [51]. It would require a Real Time Operating Systems (RTOS) for the activation of IoV services. Google's effort to develop Android-based RTOS for IoV with the help of Open Automobile Alliance (OAA) is one of the good candidates [52].

B. The Connection

The 'connection' is utilized to establish and maintain the communication between the 'cloud' and vehicles for accessing the cloud based smart services in IoV. Due to the consideration of different types of networks including VANETs, Wi-Fi, 3G/LTE, and satellite, inter connection among these networks is significantly challenging [53]. There are two major components of a connection; namely, Third Party Network Inter Operator (TPNIO) and Gateway of Internetworking (GIN). TPNIO is responsible for management of the connection whereas GIN represents the connection. Both of these components and a prioritized preference of Wireless Access Technologies (WAT) for connection are described in detail in following.

1) Third Party Network Inter Operator (TPNIO)

The need of direct Service Level Agreement (SLA) between the operators of the networks is reduced in IoV due to the consideration of TPNIO [54]. The direct SLA is a challenging constraint for any heterogeneous networks. TPNIO enables seamless roaming without compromising the quality and security of the services of network operators. The five major components for TPNIO are proposed including Global Handoff Manager (GHM), Global Authentication, Authorization and Billing (GAAB), Service Management (SM), Network Database (NDB) and Operator Database (ODB). A logical relationship among these components is shown in Fig. 11. The operational responsibilities of the components of TPNIO are described below:

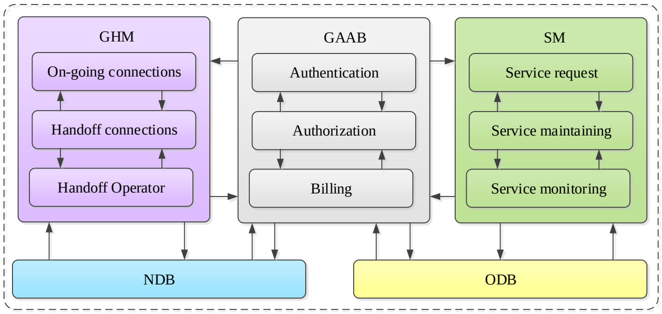

Fig. 11. The logical relationship of the components of TPNIO

- *Global Handoff Manager (GHM)*

The global handoff manager is responsible for performing seamless transfer of on-going communications between any pair of operators of the networks in IoV. It is a global handoff manager and can perform handoff operation between a pair operators of different types of networks in IoV. Development of GHM is an open research challenge in IoV for which efficient integration of handoff modules of heterogeneous networks could be consider as a general way to realize GHM [55].

- *Global Authentication Authorization and Billing (GAAB)*

The GAAB is responsible for verifying vehicle's credentials and granting permissions to access network services. The usage based pricing of network services is also handled by GAAB. The operations of GAAB is quite complex and challenging considering the fact that vehicles might belong to the operators of different types of networks. Therefore, the idea of third party is considered as a TPNIO which helps GAAB in the verification and pricing.

- *Service Management (SM)*

SM is responsible for providing and monitoring quality of service offered to vehicles. It uses service quality agreement between operators of different networks. It helps to deliver guaranteed services to vehicles using service quality agreement. Maintaining service quality between different types of networks requires consistent observation. The concept of service quality rating could be utilized for the quality maintenance.

- *Network Database (NDB)*

NDB is a databased of the registered networks with their technologies and protocols in IoV. The database is utilized to identify a network while establishing communications between the operators of different types of networks.

- *Operator Database (ODB)*

ODB is a database of the registered operators of the different types of networks in IoV. These operators have SLA with TPNIO due to which the need for direct SLA between operators is not required. The database is utilized to identify operators and their SLAs to provide guaranteed quality of service.

2) *Gateway of Internetworking (GIN)*

Due to the heterogeneous network environments in IoV, different wireless access technologies are utilized to establish connections. There are five types of vehicular networks in IoV including V2V, V2R, V2I, V2P, and V2S. The vehicular networks are represented by different wireless access technologies (see Fig. 9). The V2V and V2R networks represents vehicular communications through WAVE. The V2I network represents vehicular communications through Wi-Fi or 4G/LTE [56]. The V2P network represents vehicular personal device communications using CarPlay of Apple or Android system of OAA or Near Field Communication (NFC). The V2S network represents in-vehicle sensor communications through Ethernet, Wi-Fi or Media Oriented System Transport (MOST) [57]. These networks are utilized by client applications to access the services of smart based servers with the help of Gateway of Internetworking (GIN) (see Fig. 9). Each vehicular network has its GIN which coordinates with the TPNIO to establish and maintain a connection. The three major components of GIN are proposed including Mobility Management (MM), Local Authentication, Authorization and Billing (LAAB), and Traffic Management (TM). A logical relationship among these components is shown in Fig. 12. The operational responsibilities of these components are described below:

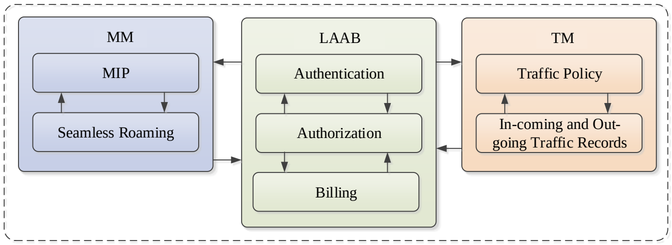

Fig. 12. The logical relationship of the components of GIN

- *Mobility Management (MM)*

MM is responsible to provide the functionalities related to Mobile IP (MIP). The concepts of Foreign Agent Vehicle (FAV) and Home Agent Vehicle (HAV) are utilized to implement MIP [58]. In IoV, a vehicle registered with a network operator is considered HAV for the operator and FAV for the other operators of the network. The seamless Roaming module communicates with GHM to perform roaming operation. The concept of tunneling could be utilized for the conversion of IP versions to avoid the restrictions of using a particular version of IPv4 or IPv6.

- *Local Authentication Authorization and Billing (LAAB)*

LAAB is responsible to provide authentication, authorization and billing services to HAV which are local users of the networks. It also helps the Global AAB (GAAB) of TPNIO for providing the same services to FAV.

- *Traffic Management (TM)*

TM is responsible to provide network traffic monitoring services by implementing the policies of the network. The policies may differ from network to network. The monitoring

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helps the network operators to provide quality of services to the client applications. The monitoring is based on the analysis of usage of traffic data as well as the live traffic data of connections.

3) *Prioritized Preference of Wireless Technologies*

Due to the heterogeneous network environment in IoV, a range of WAT would be available for client application to establish connections with smart cloud based servers. The WAT are divided into three categories; namely, vehicular, cellular mobile and small range static communications based on the communication network where WAT are utilized (see Fig. 13). These technologies have been developed for different types of communication networks. Therefore, their characteristics; i.e., strengths and limitations, are different. A prioritized preference of wireless technologies is derived in Table 1 based on the six parameters which effectively characterize these technologies. The six significant parameters of WAT include data rate, communication range, mobility support, communication delay, security support and scalability. The prioritized preference of wireless technologies would be used to select appropriate WAT for a specific client application. The appropriate technology selection would be helpful to maintaining QoS [59].

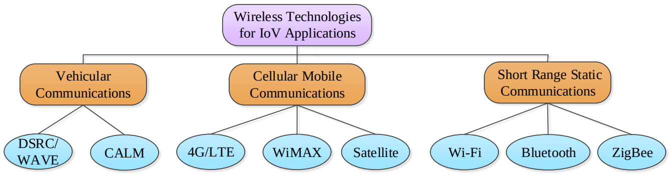

Fig. 13. The classification of WAT for the applications of IoV

Table 1. The prioritized preference of WAT

Property	**Prioritized Preference based on the Property** *High* ⟶ *Low*
Data Rate	Wi-Fi(a/b/g/n) → 4G/LTE → WiMAX → DSRC/WAVE → CALM → Bluetooth → ZigBee
Communication Range	WiMAX → 4G/LTE → DSRC/WAVE → CALM → Wi-Fi(a/b/g/n) → ZigBee → Bluetooth
Mobility Support	DSRC/WAVE → CALM → WiMAX → 4G/LTE → Wi-Fi (a/b/g/n) → ZigBee → Bluetooth
Communication Delay	DSRC/WAVE → CALM → 4G/LTE → ZigBee → Wi-Fi (a/b/g/n) → Bluetooth → WiMAX
Security Support	4G/LTE → WiMAX → Wi-Fi (a/b/g/n) → ZigBee → Bluetooth → CALM → DSRC/WAVE
Scalability	WiMAX → 4G/LTE → DSRC/WAVE → CALM → Wi-Fi (a/b/g/n)→ ZigBee → Bluetooth

C. *Client*

The services of smart cloud based servers are utilized by the 'client' applications of vehicles with the help of a network connection. The client applications or clients in IoV can be broadly divided into two categories; namely, safety and management oriented, and business oriented (see Fig. 14). Some of the potential clients and a prioritized preference of WAT for the clients are described in following sub-sections.

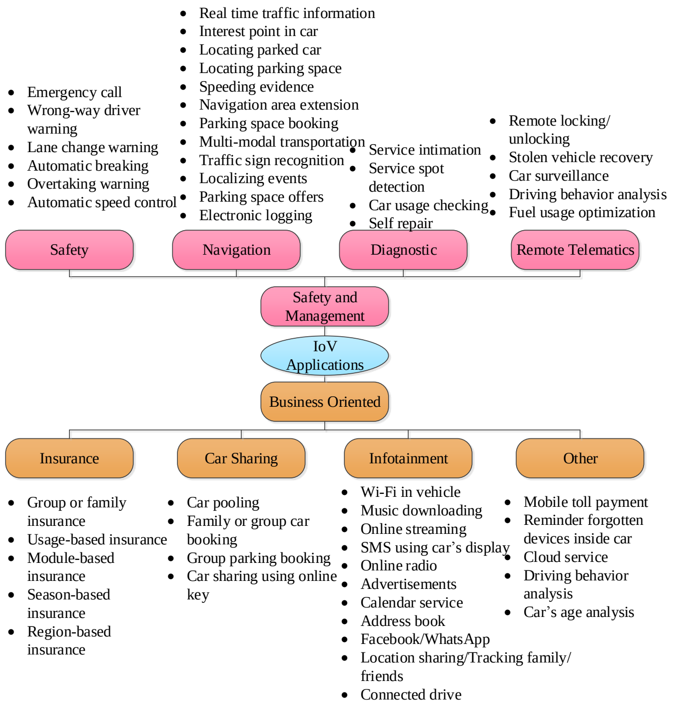

Fig. 14. The taxonomy of client applications of IoV

1) *Safety and Management Client*

Traffic safety and management related ITS applications are broadly divided into four groups including safety, navigation, diagnostic and remote telematics.

- *Safety*

The traffic safety related ITS applications are M2M communication based applications. The performance and quality of operations could be significantly enhanced by integrating cloud-based smart servers [60]. The servers utilize big traffic data to take intelligent decisions in IoV. These applications enhance driver's performance and quality of driving. The applications incorporate automatic operations on wheels, and thus, reduce the efforts needed for qualitative driving. Some of the traffic safety applications are introduced below:

Accident Prevention- It is a M2M communication system for vehicles. It prevents accidents using real time information exchange between vehicles. It enables various automatic operations including speed control, lane change, stoppage, steering control, etc. The system would be highly beneficial for highway and dense urban traffic environments. In both the environments, automatic vehicle control has significant impact on safety in case of critical situations.

Emergency Call- It is an emergency call system for vehicles. It contacts the services such as police, fire and family or friends in case of emergency. It is both automatic and manual. The call provides all the information related to the present and past situations of the vehicle. The information includes number of passengers, speed, direction, location, lane, cause of emergency, etc. This can be considered as black-box information of the vehicle.

- *Navigation*

The navigation related ITS applications are location based

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services [61]. The performance of these application are mostly dependent on the accuracy of location information. The information is obtained from the GPS receiver attached to the vehicles. These applications help in managing traffic, and thus, enhances traffic efficiency. The smooth flow of traffic and minimum carbon emission in environments are some of the key objectives of location based navigation applications. Some of these applications are introduced below:

Real Time Traffic Information- It is a traffic information system. It provides live traffic information using video sensor of vehicles and heterogeneous communication networks. This could effectively replace the current image analysis and radio broadcasting based non-real-time traffic information systems. The system relies on effective online streaming of traffic information using heterogeneous vehicular networks.

Parking Helper- It is a parking system for vehicles. It helps in finding the nearest available parking space by communicating with the parked vehicles. The system relied on accurate positioning of vehicles inside any parking infrastructure. It utilizes GPS receiver and cooperative positioning techniques. The system would reduce the wastage of fuel and time in searching parking space, particularly in dense urban traffic environment.

Multi-modal Transportation- It is a transportation system for people. It optimizes the resources including time, money, comfort, fuel, entertainment, etc., according to the choice of users. It provides route planning service including multiple means of transportation and optimizing user's preference. The system would be one of the most innovative applications of IoV for the current urban scenarios. This is due to the different modes of intra and inter-city transportations availability.

- *Diagnostic*

Vehicle diagnostic related applications works as personal health consultant for vehicles [62]. Apart from real time monitoring overall condition of vehicles, cloud-based data management of vehicle's condition is one of the key operations of these applications. The cloud-based diagnostic data is used for online prediction and maintenance advisory to vehicles. Diagnostic applications would reduce maintenance cost. The applications timely intimate the need of repair and rightly intimate the service spots. One of the diagnostic clients is described below:

Self-Repair- It is a cloud-based step-by-step repair guidance system. It helps the owner of vehicle in fixing hardware/software issues of the vehicle. The system is relied on a cloud based database. The database evolves automatically with the advancements in the technology. The clear guidance is available for all kinds of vehicles through audio and video technologies. The system would significantly reduce the amount of money spent in repairing. It could reduce the overall vehicle ownership cast.

- *Remote Telematics*

Remotely accessing some of non-driving operations of vehicles could be made possible by using highly secure remote telematics applications [63]. The applications are based on accurate remote tracking, authentication and authorization methods. These applications are actually the conversion of traditional physical entity based operations into digital entity based operation. The applications enhance the ease of usage of and monitoring of vehicles. Some of the examples in this category include remote locking/un-locking, car surveillance, etc.

2) *Business Oriented Client*

The business oriented ITS applications of IoV can be broadly divided into four categories including insurance, car sharing, infotainment and other applications.

- *Insurance*

The insurance based ITS applications are different models for providing insurance. The models are based on some statistical analysis of information including usage of vehicles, driving behavior, place of usage and time duration of usage [64]. These applications would reduce insurance cost, and thus, optimize vehicle ownership cost. One of the insurance based applications is introduced below:

Insurance on Driving Statistics- It is an insurance system for vehicles. It automatically calculates insurance fee by utilizing the driving statistics information. The information includes daily/monthly/yearly driving duration or how much you drive and daily/monthly/yearly violations of traffic rules or how you drive. The system is completely relied on the cloud based vehicle usage statistics. It could significantly optimize cost of insurance.

- *Car Sharing*

The car sharing ITS applications are based on the concept of improving the utilization of resources while using cars, and thus, reducing the cost incurred in transportation. This can be achieved by travelling by car in groups. One of the car sharing applications is introduced below.

Car Pooling- It is a car sharing application based on cloud platform. It allocates car service seekers to car owner. The allocation is based on the optimization of matching criteria of passengers. The criteria include local address, work place, timing, gender, age, and employment position. In the application, the registration of car owners and car service seekers are verified by the service provider.

- *Infotainment*

Evolving from the concepts of connected home, office and mobility, now the time is for connected drive. It is the core concept of the infotainment ITS applications of IoV [66]. These applications rely on reliable Internet connectivity. The application would enhance productivity and travel experience by being on-line while driving. One of the infotainment applications is introduced below:

Connected Driving- It is a device synchronization system for vehicles. It connects vehicle's display unit to office or home computer, smartphone and other online devices. The system is based on remote login in different types of online devices with security credentials. The system would improve productivity in driving duration while avoiding on-road fatalities. This is due to the utilization of automatic support applications for drivers in IoV.

- *Others*

There are some other applications which do not fall into the aforementioned categories. The applications are very useful in

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terms of commercialization of traffic services. These applications are based on different business concept and technologies. One of the applications in this category is introduced below:

Cloud Service- The cloud system either forms autonomous cloud of group of vehicles or connects the vehicles to traditional cloud. In either case, the resources of connected vehicles are available for usage as cloud service as well as the vehicles can utilize smart cloud services. The system would eliminate computational and storage limitations at vehicles. It could open new business models in connected drive.

3) Prioritized Preference for Clients

The aforementioned client applications have different service requirements in terms network parameters. The service requirements depends on the type of applications or the key objectives of the applications. A prioritized preference WAT for each type of client is obtained in Table 2 by utilizing the prioritized preference of Table 1. The prioritized preference would be used by clients to select appropriate WAT while establishing connection.

Table 2. The prioritized preference of WAT for clients

Application	Service Requirement	Prioritized Preference *High* → *Low*	Ref.
Safety	Life critical applications require lower communication delay and delivery guarantee.	DSRC/WAVE → CALM → 4G/LTE → ZigBee → Wi-Fi→ Bluetooth → WiMAX	[60]
Navigation	Traffic efficiency oriented navigation applications require better mobility support, security and privacy scalability	DSRC/WAVE and WiMAX → CALM and 4G/LTE → WiMAX and DSRC/WAVE→ 4G/LTE and CALM → Wi-Fi → ZigBee → Bluetooth	[61]
Diagnostic	Ownership cost optimizer diagnostic applications require better communication range and data rate to continuous monitor vehicles	WiMAX and Wi-Fi → 4G/LTE → DSRC/WAVE and WiMAX → CALM and DSRC/WAVE → CALM and Wi-Fi → Bluetooth and ZigBee	[62]
Remote Telematics	Authentication and authorization based remote telematics applications require better security and communication range for reliable remote accessing.	4G/LTE and WiMAX → Wi-Fi and DSRC/WAVE → ZigBee and CALM → Bluetooth and Wi-Fi → DSRC/WAVE and Bluetooth	[63]
Insurance	Cost optimizer insurance applications require scalability and security to monitor of vehicular statistics.	WiMAX and 4G/LTE → DSRC/WAVE and Wi-Fi → CALM and ZigBee → Wi-Fi and Bluetooth → ZigBee and CALM → Bluetooth and DSRC/WAVE	[64]
Car Sharing	Resource utilization oriented car sharing applications require mobility support and scalability for durable connectivity to all users.	DSRC/WAVE and WiMAX → CALM and 4G/LTE → WiMAX and CALM → 4G/LTE and Wi-Fi → ZigBee and Bluetooth	[65]
Infotainment	Online streaming based infotainment applications require better data rate and mobility support for durable connectivity.	Wi-Fi and DSRC/WAVE → 4G/LTE and CALM → DSRC/WAVE and 4G/LTE → CALM and Wi-Fi → Bluetooth and ZigBee	[66]

V. BENEFITS OF INTERNET OF VEHICLES

In this section, benefits of IoV is examined into two aspects. Firstly, IoV is compared with traditional vehicular communication; i.e., VANETs. Secondly, IoV is evaluated in the context of two new paradigm in vehicular communication; namely, Cyber-Physical System (CPS) and Named Data Networking (NDN).

A. IoV over VANETs

A comparative investigation between IoV and VANETs is carried out to highlight the fruitful impact of the realization of IoV on vehicular communication, its services, and business orientation of the communication (see Table 3). Specifically, fifteen parameters are considered for the comparative assessment including Commercialization (CM), Objectives (OB), Network Architecture (NA), Internet Service (IS), Communication Types (CT), Device Compatibility (DC), Processing Capability (PC), Data Size (DS), Decision Making (DM), Cloud Computing (CC), Autonomous Cloud (AC), Application Service (AS), Scalability (SC), Connectivity (CO) and Network Awareness (NAW). The following remarks can be made from this comparative assessment.

- The vehicular communications of IoV would be highly commercialized. This is due to the smart commercial and infotainment applications in addition to the smart safety, management and efficiency applications.
- The network architecture of IoV would integrate vehicular communication with other communication networks. This is due to the heterogeneous network architecture.
- IoV would provide reliable Internet service in vehicles. This is due to the inclusion of V2I communication.
- Most of the existing computing and communication devices in our daily would be compatible with vehicular networks of IoV.
- The processing and decision making capability of vehicles, size of vehicular networks, volume of network data would enlarge drastically in IoV.

Table 3. The qualitative comparison between IoV and VANETs

Parameter	IoV	VANETs
CM	Huge opportunity for commercial applications due to the business oriented architecture and reliable Internet connectivity.	Not able to attract commercial interest due to the non-supportive architecture for commercial applications and unavailability of Internet [67].
OB	Traffic safety, efficiency and commercial infotainment.	Traffic safety and efficiency [68].
NA	Collaborative internetworking among heterogeneous networks.	Singleton network architecture which is not able to collaborate with other existing networks [69].
IS	Reliable Internet service would be available.	Internet service is not available due to the non-collaborative network architecture [70].
CT	Five types of communications including V2V, V2R, V2I, V2P and V2S.	Two types of communications including V2V and V2R [71].
DC	Most of the personal devices are compatible with the network and able to	Communication compatibility between personal devices and the network is still a challenging

	communicate with vehicles including smart phones, laptop, tablets.	issue due to the singleton network architecture [72].
PC	The best processing capacity available due to the on-demand cloud based service.	Limited processing capability due to the stand alone system availability [73].
DS	Big data due to the collaboration of different types of networks.	Limited data due to the consideration of only neighboring vehicles statistics in the operation and decision making [74].
DM	Decisions related to applications and protocols are based on AI based data mining and big data computation.	Decision are based on simple and logical computation on local data because the usage of AI is still a challenging task due to the resource limitations [75].
CC	All the operation is based on cloud computing and big data analysis which make IoV more intelligent.	Cloud based operation is possible but currently not supported due to the unavailability of reliable Internet connectivity [76].
AC	Cloud formation, management and services are efficient and reliable.	Cloud formation is possible but management and services are not guaranteed [77].
AS	The services of ITS applications will be efficient and reliable due the client-server architecture using Internet connectivity.	No ITS applications guarantee about the service availability due the network disconnection issue [78].
SC	Due to the capability of collaborative integration among different types of networks (VANETs, Wi-Fi, 4G/LTE) the network architecture is scalable	Due to the inability of collaborative operation, the network architecture is not scalable [79].
CO	Vehicles are all time connected to the network through the best available network.	Vehicles get connected and disconnected from the network depending on the availability of the network [80].
NAW	Due the availability of cloud based computation and storage services, global network awareness is utilized for enhancing the performance of the network.	Network awareness is reduced to the neighbor awareness due to the unavailability of information and storage and processing constraints of a vehicle [81].

B. IoV in the Context of CPS and NDN

Vehicular Cyber Physical System (VCPS) is new paradigm in vehicular communication [82, 83]. It has emerged due to the growing importance of cloud based intelligent computation in big traffic data and efficient dissemination of information using next generation Internet [84, 85]. There are five major modules of VCPS including sensing, data management, next generation Internet, services and applications [86, 87]. The proposed architecture and network model of IoV precisely support VCPS as next generation Internet. Intelligent computation in big traffic data using cloud computing for non-safety services and fog computing for safety services is the core of VCPS, and the same is supported in the layered architecture of IoV as artificial intelligence layer [88, 89]. The cyber world and physical world in VCPS is depicted in Fig. 15.

Vehicular Named Data Networking (VNDN) is another novel networking concept in vehicular communication. VNDN enables address-less communication among vehicles [90]. It has significant potential to mitigate unique address management for vehicles in vehicular communication. VNDN is based on the concept of addressing an 'interest' rather than a vehicle. Its Interest/Data based communication is highly suitable for vehicular communication due to the distributed nature of vehicular network environments. VNDN could significantly reduce network load and optimize network performance [91]. Due to the inclusion of different types of devices with vehicular communication in IoV, the idea of address-less communication of VNDN is a prospective concepts for IoV. In IoV, VNDN could be extended to support address-less communication not only in vehicle-to-vehicle communication but also in vehicle-to-devise communication with the devices attached to address-based networks. The extended VNDN would effectively support the idea of global heterogeneous networking of IoV. The extended VNDN is depicted in Fig. 16 with Interest/Data based communications among vehicles as well as devices.

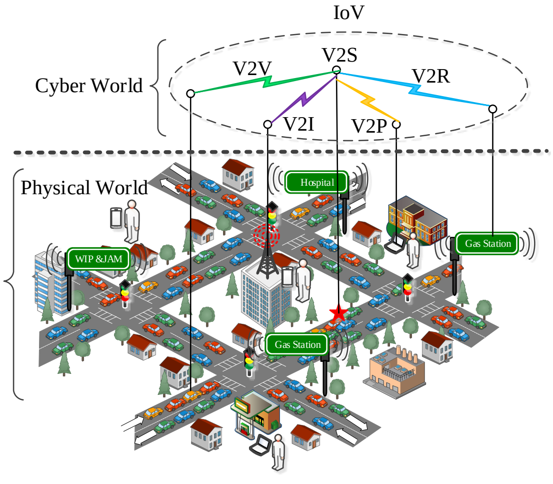


Fig. 15. The cyber and physical world of VCPS

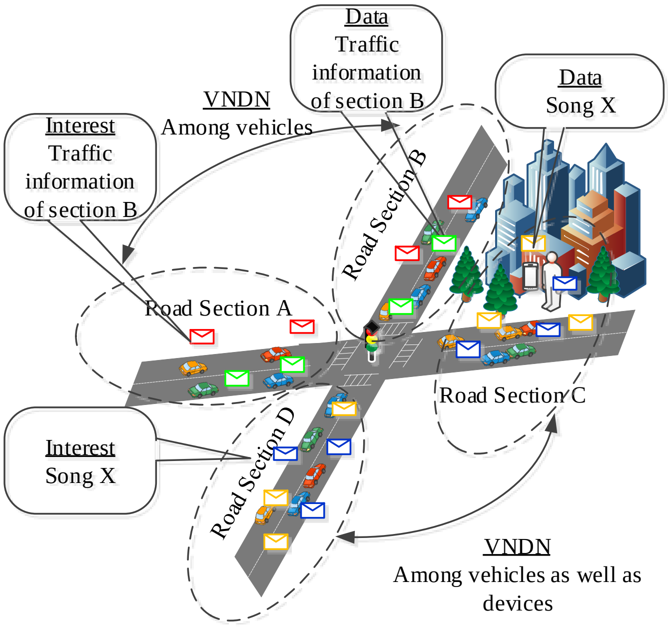


Fig. 16. VNDN among vehicles as well as devices in IoV

VI. CHALLENGES AND ISSUES

The complete realization of IoV could bring fundamental changes in driving experience by integrating smartness into ITS applications. Apart from driving, other related areas including urban traffic management, automobile production, repair and vehicle insurance, road infrastructure construction and repair, logistics and transportation would also positively transformed. The cost effectiveness in these areas would be a major contribution of IoV. This is due to the collaborative integration of available information for optimizing cost. However, realizing IoV would be a significantly challenging task. Various issues of vehicular communications are yet to be resolved for the realization of IoV. Some of challenges are described below considering their specific issues.

A. Localization Accuracy

Accurate localization of vehicles is significantly challenging considering the accuracy requirement in vehicular communication environments. The accuracy requirement is quite higher than the accuracy provided by existing GPS-based localization [92]. In fulfilling the accuracy requirements, following three issues are needed to address.

- GPS-based localization provides accuracy of 5 m whereas the accuracy requirement in vehicular communication environments is 50 cm [93].
- GPS-based localization do not take speed of the objects into consideration whereas speed is one of the important constraints in vehicular communication environments [94].
- Deteriorated quality of GPS signal or even unavailability of signal in dense urban environments [95].

B. Location Privacy

Due to the highly mobile adhoc network environment, vehicular communications are based on periodic beaconing information about the network. The periodic beaconing information includes location, velocity, direction, acceleration, and vehicle type [96]. The revealing of location information results into huge privacy concern. The vehicles have to utilize location information for communication without exposing the information itself. Therefore, the location privacy is a quite challenging task [97]. Although some techniques including pseudonym [98], silent period [99] and mix zone [100] have been suggested to address the privacy concern yet, the concern is unresolved. This is due to the below listed issues in the privacy techniques.

- Pseudonym switching is workable in case of higher vehicle density. The technique is easily detectable in lower vehicle density environments.
- Silent period is applicable for non-real time ITS applications. The technique is not suitable for real time applications.
- Mix zone is useful on multi lane roads with larger zone area. The technique is not effective on one way roads.

C. Location Verification

Location verification of neighboring vehicle is another challenging problem in vehicular communication. This is due to the absence of trusted authority in vehicular communication. Some of the techniques suggested for location verification including directional antenna [101], beaconing based belief [102], and cooperative approach [103]. The following issues need to be addressed in these techniques.

- The cost of infrastructure in directional antenna approach. The limitations of range based techniques in vehicular environment.
- The overload involved in the beaconing approach.
- The untrustworthy neighbour in cooperative verification.

D. Radio Propagation Model

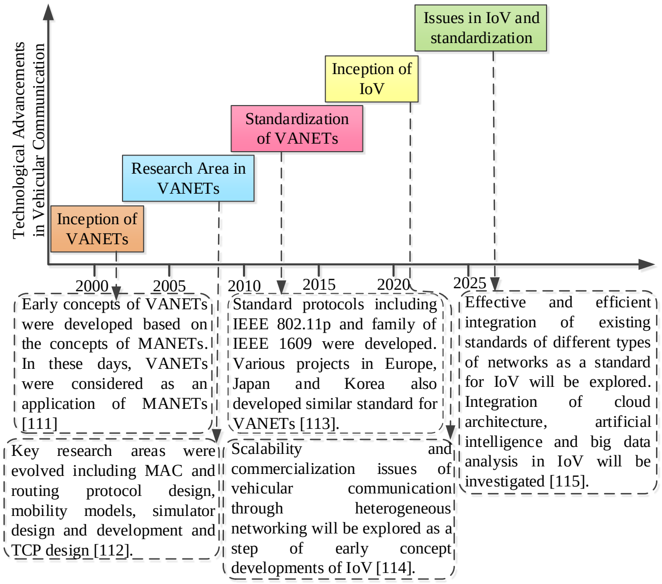
Radio propagation in vehicular traffic environment is considerably deteriorating. This is due to the modern road infrastructure and speed of vehicles. The radio obstacles on and alongside roads can be categorized in moving and static radio obstacles. The moving obstacles on road includes trucks, buses and other larger size vehicles. The static obstacles include buildings alongside road, flyovers, underpasses and tunnels [104]. Currently, wireless propagation models of mobile communications are used in vehicular communications, and thus, the impact of aforementioned obstacles on the radio propagation in vehicular environments is not considered [105]. Moreover, the WAVE standard for vehicular communication uses 5.9 GHz frequency which has lesser penetration capability as compared to well-known Wi-Fi and mobile radio signal. Therefore, following concerns are need to be addressed for developing accurate radio propagation models for vehicular communications.

- Incorporation of the impact of moving and static obstacles in radio propagation models for vehicular communications [106].
- Maintaining accurate line-of-sight in vehicular communications considering the lower penetration capability of 5.9 GHz vehicular radio frequency.

E. Operational Management

Due to the collaboration and coordination among different types of networks, the volume of data in IoV would drastically increase. Therefore, operational management in terms of security and credibility would be significantly challenging. Vehicles would be equipped with number of sensors, different types of radio terminals, and transponders. As a result, a multi-attribute network would emerge where the traditional network operators such as ISP, telecom operators, automobile companies and dealers would collaborate and work under third party virtual network operator. Apart from the equipment related complexities, computational complexities would be also challenging due to the consideration of cloud computing in highly mobile network environment.

Apart from the aforementioned challenges and issues, there are other issues related to disruption reduction [107], opportunistic framework [108], geographic routing [109], and MAC standard [110]. The issues have been explored up to some extend in the context of existing vehicular communication architecture. A thorough investigations are needed in the context of the framework of IoV. These issues are not discussed here in detail due to the space limitation.



Early concepts of VANETs were developed based on the concepts of MANETs. In these days, VANETs were considered as an application of MANETs [111]

Key research areas were evolved including MAC and routing protocol design, mobility models, simulator design and development and TCP design [112].

Standard protocols including IEEE 802.11p and family of IEEE 1609 were developed. Various projects in Europe, Japan and Korea also developed similar standard for VANETs [113].

Scalability and commercialization issues of vehicular communication through heterogeneous networking will be explored as a step of early concept developments of IoV [114].

Effective and efficient integration of existing standards of different types of networks as a standard for IoV will be explored. Integration of cloud architecture, artificial intelligence and big data analysis in IoV will be investigated [115].

Fig. 17. Evolution of vehicular communication from VANETs towards IoV

VII. FUTURE ASPECTS

The future aspects of IoV is bright with the assumption that the aforementioned challenges and issues would be resolved. A summarized view of the evolution of vehicular communication is depicted in Fig. 17 for making a clear picture of IoV ahead. IoV would bring novel features in every field of automobile right from the manufacturing up to the customer experience. Some of these features of future vehicular communications are introduced below.

- **Online Vehicle**- Each vehicle would be online right from the completion of manufacturing up to the usage by customers. Most of the services related to vehicle would be available online. The services include status of vehicles, annual inspection report by authority, road tax payment status, repair or service history, etc. The management cost of vehicle would be drastically reduced. This is due to the online availability and timely intimation of service related information.
- **Global Internet ID**- Each vehicle would have a uniquely identifiable number in Internet which is a prerequisite for online presence of vehicles. Inspite of deficiencies, GPS based identification is started by various organizations of GOVTs for enhancing safety in public transport. The global Internet ID would eliminate the need of GPS based vehicle identification approach. The issues related to the accountability in accidents, falsification in registration and unauthorized modification would be addressed with more credibility. Black box in vehicle kind of service would be made possible with the inclusion of global Internet ID.
- **RFID+GPS**- The integration would greatly expand the operational framework of current ITS. This is due to the opportunity of new domains for ITS applications as well as efficiency and service quality enhancement in existing application domains. RFID based secure identification of global ID and GPS based real time positioning would redefine the performance of protocols. The real time and intelligent route discovery would be possible for information dissemination. The protocol performance has considerable impact on overall performance of ITS applications. Therefore, it would result in improved customer experience and traffic management.
- **On-road Internet**- The reliable Internet services in vehicles would add new devices in on-line cyberspace in large volume. This is due to the inclusion of all on-road vehicles. This will open new research and development themes in protecting online privacy and generating trusted ID.
- **Big Business Data**- The cloud based integration of heterogeneous networks with vehicular network would result as a huge data resource. The resource could be utilized in productive manner with wide range of businesses including automobile, Internet, insurance and market analysis. Management of big business data would be significantly challenging in IoV in terms of cloud based storage, processing and digital distribution.
- **Smart Terminal**- Machine-to-machine communication based smart terminals would be on demand for both in-vehicle and handset usage. The terminals would be capable to provide most of the location based services by collaborating with IoV.
- **Car Payment**- Unique cyber space identity would enable car payment. The information of driver or owner of vehicle and would become an alternative of mobile payment. It would be a significant step in terms of acquisition of economic identity by vehicles. Car payment would enhance efficiency of traffic management. This would be in terms of hassle free toll collection, fuel refilling, parking collection, road tax collection, and even payment for service and management.

VIII. CONCLUSION

Internet of Vehicles (IoV) is evolving as a global heterogeneous vehicular networks. The emerging concept of ‘Connected Drive’ in smart transportation is the basis of IoV. The two major objectives of IoV include automation of various security and efficiency features in vehicles and commercialization of vehicular networks. In this paper, a comprehensive framework of IoV is presented. In turn, this should provide a foundation to gain insight and overall understanding of IoV. The researchers and practitioners who are interested in future vehicular communications would be benefited. The benefits would be in terms of understanding the layered architecture, network model and challenges of IoV. The smart applications for safety, efficiency and commercialization, and the prioritized preference of WAT should help vehicular application and technology developers. The developers would be benefited in technology oriented application development and application based technology advancements. The identified challenges and issues in the design and development of IoV should get the investigative attention of researchers. Future aspects should help in clear envisioning of IoV in terms of the benefits over VANETs.

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