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# Deployment of IoV for Smart Cities: Applications, Architecture, and Challenges

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**ABSTRACT** The Internet of Vehicles (IoV) is a convergence of the mobile Internet and the Internet of Things (IoT), where vehicles function as smart moving intelligent nodes or objects within the sensing network. This paper gives two contributions to the state-of-the-art for IoV technology research. First, we present a comprehensive review of the current and emerging IoV paradigms and communication models with an emphasis on deployment in smart cities. Currently, surveys from many authors have focused concentration on the IoV as only serving applications for intelligent transportation like driver safety, traffic efficiency, and infotainment. This paper presents a more inclusive review of the IoV for also serving the needs of smart cities for large-scale data sensing, collection, information processing, and storage. The second component of the paper presents a new universal architecture for the IoV which can be used for different communication models in smart cities to address the above challenges. It consists of seven layers: vehicle identification layer, object layer, inter-intra devices layer, communication layer, servers and cloud services layer, big data and multimedia computation layer, and application layer. The final part of this paper discusses various challenges and gives some experimental results and insights for future research direction such as the effects of a large and growing number of vehicles and the packet delivery success rate in the dynamic network structure in a smart city scenario.

**INDEX TERMS** Internet of Vehicles, IoV, layer architecture, smart city, applications, big data.

## I. INTRODUCTION

The recent advanced growth of large-scale networked sensors, computation and communication technologies and cloud infrastructure have made the realization of smart cities possible in the near future [1]–[3]. In a smart city scenario, many physical objects, or more precisely 'smart' objects with its own processor, computing and communication power can interact with each other. These smart objects which would provide a safe and smart environment through increased interconnection and interoperability is also called as the Internet of Things (IoT). Within the objectives of the IoT, many such objects will be connected vehicles or cars which can communicate and interact wirelessly with various types of devices connected to the Internet, devices in the car (intra-vehicle) or outside of the car (inter-vehicle). This leads to a specific type and customized IoT called the Internet of Vehicles (IoV) which achieves unified management in intelligent transportation and other applications in smart cities.

The concept of smart cities emerged as a strategy to mitigate the challenges of rapid and continuous urbanization while at the same time to provide better quality of life to its citizens [4]. Smart cities [13], [14] are characterized by extensive use of digital technologies and diverse forms of interactions (e.g. human-to-human, human-to-machine, machine-to-machine) which generate huge volumes of data commonly termed as Big data [5], [6], [16].

The IoV can be considered as a convergence of the mobile Internet and the traditional IoT. As a huge network of interactions, IoV technology refers to dynamic mobile communication systems or models that communicate between vehicles and other objects using V2V (vehicle-to-vehicle), V2R (vehicle-to-road), V2I (vehicle-to-infrastructure), V2B (vehicle -to-building), V2H (vehicle-to-home), V2X (vehicle-to- everything), V2G (vehicle-to-grid), and V2H (vehicle-to- home) interactions. It also allows information exchanges between V2D (vehicle-to-device), V2S (vehicle-to-sensor) and D2D (device-to-device) within a vehicle. A deployment of the IoV in smart cities enables information sharing and the gathering of Big data information on vehicles, roads, infrastructure, buildings, and their surroundings. The IoV ecosystem can provide services for intelligent transportation applications to guide and supervise vehicles, and provide abundant multimedia and mobile Internet application services.

Currently, surveys of the IoV from many authors [7]–[9] have focused concentration on the IoV as only serving applications for intelligent transportation systems (ITS) like driver safety, traffic efficiency, and infotainment. To the best of our knowledge, the potential and usage of the IoV for also serving the needs of smart cities for large-scale data sensing, collection, information processing, and storage have not been comprehensively investigated and surveyed. An important issue in smart city environments is the challenge to collect or deliver data to hundreds of thousands of sensors and actuators integrated within smart objects (e.g. garbage cans, drainage and building infrastructures). Shah *et al.* [10] propose to use vehicles as data MULEs (Mobile Ubiquitous LAN Extensions) to opportunistically collect and distribute the data in the smart city environment. Other examples of application of the IoV in a smart city is for environmental monitoring (e.g. air pollution [11]), waste management [12] and to perform urban surveillance for monitoring sensitive areas and to identify suspicious behavior. In this IoV scenario, the cameras located on vehicle objects could be utilized to contribute to performing the surveillance task. This also introduces the need of the IoV to handle multimedia data like images and video. This paper aims to fill this research gap and presents a more inclusive review of the IoV for also serving the needs of smart cities for large-scale data sensing, collection, information processing, and storage. A final note is that although the focus would be on utilizing land-based vehicles as smart moving intelligent nodes in the IoV, the discussions can also be applied towards the usage of air-based vehicles [95] and water-based vehicles [96].

One of the main challenges of the IoV for deployment in smart cities is the integration of all components and object communications in the IoV ecosystem. Several authors have proposed IoV architectures based on layered designs [20]–[24] to meet these requirements. However, as noted above, these designs are specifically tailored to meet the needs of ITS applications and do not consider the general scenario of smart city environments and Big data processing. The second challenge is the rapid growing number of vehicles and other objects connected to the IoV and the large scale of data collection between vehicles and application platforms. This challenge conforms to the heterogeneous nature of Big data in size, volume, and dimensionality. This leads to the need of Big data processing and analytics which aims to draw meaningful insights for research and commercial benefits. It should be noted that many existing proposed IoV architectures [25]–[28] give no or inadequate consideration to Big data collection, processing and analytics in their architectures. The recent work in [19] only focused on the secure mechanism for Big data collection in IoV. Besides that, the escalating growth of multimedia content from the objects within the vehicle and between the vehicle and application platforms also leads to a huge volume of multimedia data such as text, audio, images and video, etc. Therefore, a new universal IoV architecture which can address the above challenges is highly desired.

This paper presents a new universal architecture for the IoV which can be used for different communication models to serve the needs of smart cities. We first present a comprehensive review of research works on existing IoV architectures and different communication models for deployment in smart cities. Then we consider the issue by contemplating the concept of IoT, drawing an inspiration towards the perspective vision of IoV, and subsequently propose the Universal IoV (UIoV) as a novel paradigm in which the universal architecture can be used for different communication models in smart cities. In addition, the Big data processing and analytics are considered and smart heterogeneous multimedia things which can interact and cooperate with one another and with other things connected to the Internet to facilitate multimedia based services and applications that are globally available to the users. Fig. 1 gives an overview of the proposed UIoV. The UIoV architecture consists of seven layers: Vehicle Identification Layer, Object Layer, Inter-Intra Devices Layer, Communication Layer, Servers and Cloud Services Layer, Big Data and Multimedia Computation Layer, and Application Layer. The specific layers or sub-layers in this proposed architecture are designed to consider scalar and multimedia objects, intra-devices within a vehicle, inter-devices between vehicles and platforms, Big data, multimedia data, etc. The Big data computation layers have functional units for Big multimedia processing and analytics.

There are several challenges (technological and social) which have to be addressed for deployment of the IoV in smart cities. When there is a growing number of vehicles connected to the IoV in the smart city, this indicates the increasing number of vehicle nodes (moving nodes) before the Big data collection. This causes some effects of packet successful delivery to sink nodes. The speed of vehicle nodes is also a factor for the packet delivery rate. The dynamic network structure of the IoV further increases the complexity of the packet delivery success rate. The existing works in IoT do not take these into consideration, and thus they cannot be directly applied in IoV with Big data collection. Another contribution of this paper is to investigate future challenges and the effects of the aforementioned factors on the moving nodes in a smart city scenario. Some experimental results are given to provide insights and information for future research direction.

The remainder of the paper is organized as follows. Section II gives background information and classifications for previous IoV research. Section III gives discussions of applications in the IoV from two perspectives: (1) Applications for intelligent transportation (ITS); and (2) Applications for smart cities related applications. Section IV presents a

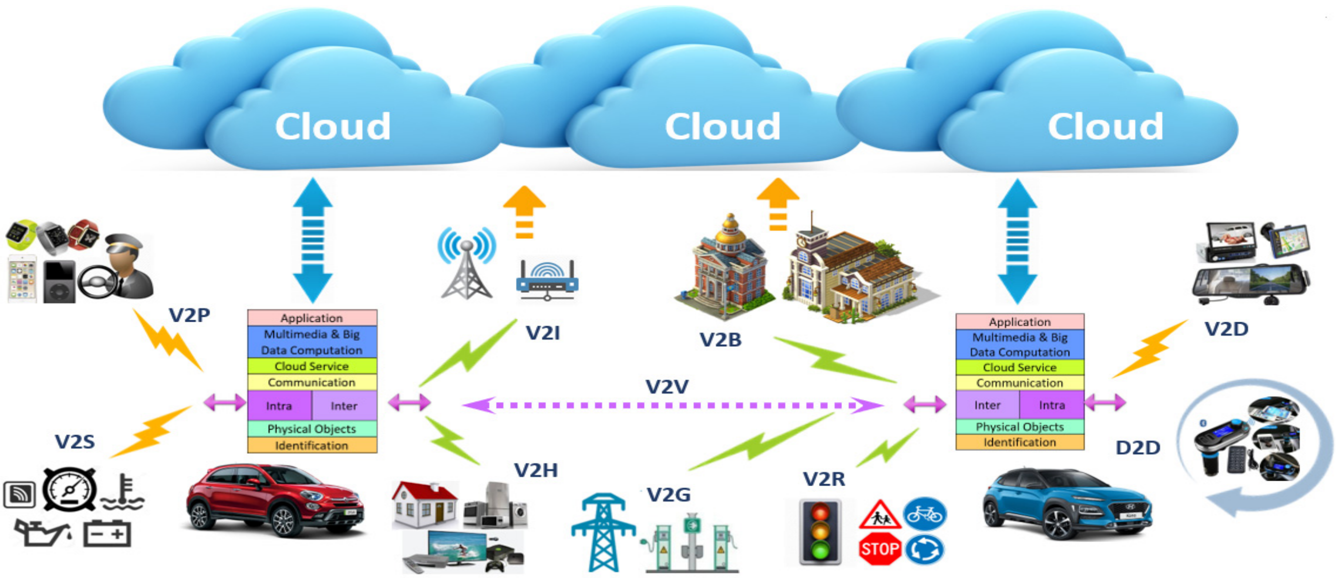


**FIGURE 1.** An universal internet of vehicle (UIoV) for smart cities.

review of works on IoV layer architectures and interaction communication models. A new universal IoV (UIoV) architecture for smart city deployment is presented in Section V and Section VI gives further discussions for the Big Data and Multimedia Computation Layer in the UIoV architecture. Section VII discusses some technical and social challenges for IoV deployment in smart cities. This section also gives some experimental results for IoV networks in smart cities to provide insights for future research. Finally, Section VIII gives some concluding remarks.

## II. OVERVIEW AND CLASSIFICATION

This section gives an overview and classification of IoV research. The works are classified into different categories based on the following: (1) IoV applications; (2) IoV architectures and vehicle interaction models; and (3) IoV challenges. Table 1 shows the classification of IoV research for smart cities which also gives a concise summary of the overall scope of the paper.

## III. IoV APPLICATIONS

This section discusses IoV applications from two perspectives: (1) Applications for intelligent transportation (ITS); and (2) IoV for smart cities related applications. The rationale for having these two perspectives is that many surveys from authors have focused concentration on the IoV as only serving applications for ITS like driver safety, traffic efficiency, and infotainment. The potential and usage of the IoV for also serving the needs of smart cities for large-scale data sensing, collection, information processing, and storage have not been comprehensively investigated and surveyed. ITS-based IoV applications primarily serve the needs for the individual vehicle objects and the requirements for the IoV network itself. On the other hand, for IoV smart cities applications,

**TABLE 1.** Overall classification of IoV research.

| Classification | References |
|---|---|
| Applications | |
| ITS-based IoV applications | [29],[30],[31],[32],[33],[34],[35],[36],[37],[38],[39] |
| Smart cities IoV applications | [11],[40],[41],[42],[94],[95],[96],[97],[98],[99],[100] |
| Architectures and Vehicle Interaction Models | |
| Layer architectures | [20],[21],[22],[23],[24],[25],[26],[27],[28] |
| Vehicle-to-Vehicle (V2V) | [27],[43],[44],[45],[46],[47] |
| Vehicle-to-Roadside (V2R) | [48],[49],[50],[51],[52],[53],[54] |
| Vehicle-to-Infrastructure (V2I) | [45],[55],[56],[57],[58],[59],[60],[61],[62],[63],[64] |
| Vehicle-to-Building (V2B) | [51],[65] |
| Vehicle-to-Home (V2H) | [66] |
| Vehicle-to-Everything | [44],[67],[68],[69] |
| Vehicle-to-Grid (V2G) | [65],[70],[71],[72],[73],[74] |
| Vehicle-to-Pedestrian | [75],[76],[77] |
| Challenges | |
| Technological challenges | [18],[101] |
| Social challenges | [11] |

the vehicle objects in the IoV serve the needs of the thousands of objects within the smart cities for opportunistic data collection, information transportation, processing, and storage. Table 2 shows a summary of IoV applications and examples of works for the two perspectives for ITS and smart cities IoV applications and for different categories and classifications.

### A. ITS-BASED IoV APPLICATIONS

IoV applications for intelligent transportation can be broadly classified into four major categories: (1) Safety-based; (2) Efficiency-based; (3) Comfort-based; and (4) Information/ Entertainment-based applications. The primary goal for safety-based IoV applications is to avoid or decrease the number of accidents by detecting potential situations for collisions within the transportation system. These are known as collision avoidance systems (CAS) or cooperative

**TABLE 2. Summary of IoV applications.**

| Category | Examples of Works and Characteristics |
|---|---|
| Applications for Intelligent Transportation (ITS) | |
| Safety-based | Collision avoidance systems (CAS) [29], [30], [31], [32] |
| Efficiency-based | Traffic signal scheduling [33], [34], [35], cooperative driving [36] |
| Comfort-based | VANET smart parking [94] |
| Information/ Entertainment-based | Vehicle QoS-enabled Internet access [37], vehicular video streaming [38], [39] |
| Smart Cities Related IoV Applications | |
| Large-scale data collection | Taxi cabs as mobile nodes (Rome) [40], Vehicle OBUs for video, noise, gas, meteorological sensors (Porto) [41], Mobile vehicles and data centers (Beijing) [42] |
| Environmental monitoring | Air quality monitoring [11], [95], VSNs with gas sensors, GPS, wireless interfaces, social reward policy [11], HazeWatch (Sydney) [96] |
| Structural and road monitoring | Bridge health monitoring [97], road condition monitoring [98], CarMote [99] |
| Healthcare | Telemedicine infrastructure MULEs [94] |
| Security/surveillance | Urban monitoring (MobEyes) [100] |

collision avoidance systems when the CAS information is distributed to neighboring vehicles in the IoV. The work by Hafner *et al.* [29] proposed an approach using V2V for cooperative collision avoidance at intersections. The authors proposed decentralized algorithms for two-vehicle cooperative collision avoidance at intersections using formal control theoretic methods to guarantee a collision-free system. Their work was validated in a test track on two instrumented vehicles engaged in an intersection collision avoidance scenario. Another work by Taleb *et al.* [30] proposed a strategy for effective collision avoidance in vehicular networks termed the C-RACCA system. The C-RACCA forms clusters of vehicles that belong to the same group using a number of features pertaining to the movements of the vehicles and an emergency level is associated with the vehicle that signifies the risk of encountering a potential collision scenario. Other examples of CAS applications can be found in [31] and [32].

Efficiency-based applications aim to improve the mobility of the vehicle objects within the IoV network. An example application is the scheduling of traffic signals at intersections based on the traffic volume to reduce the waiting time. The work in [33] proposed a V2V-based approach by clustering vehicles approaching the intersection. The density of vehicles within the cluster is calculated and the information is sent to the traffic-signal controls to set the timing cycle. Another work in [34] proposed a fuzzy logic approach for scheduling the signalized intersection with the objective of maximizing both traffic efficiency and fairness. Their approach used two stages. At the first stage, a green-phase selector was developed to select the subsequent green phase. At the second stage, a green-time adjustor was proposed to determine the green time for the selected phase. The work in [35] proposed a fuzzy traffic control approach by utilizing V2X communication. Another example of efficiency-based applications can be found in [36] for cooperative driving which proposed modeling trajectories in advance for vehicles in the vicinity of traffic signals to reduce stopping frequency and travel time and improve the throughput of the road according to traffic conditions and the situation regarding adjacent vehicles.

Comfort-based IoV applications aim to give information to drivers to make the trip comfortable and enjoyable. This may include weather, route navigation, information on parking lots [92], locations of tourist information kiosks, restaurants, petrol stations, etc. Information/entertainment-based applications aim to distribute entertainment-related information to drivers and passengers. This would include access to the Internet and other file-sharing services. Currently, giving vehicles access to the global Internet and keeping the information up to date is a challenging task because of the dynamic and changing nature of the vehicle objects in the IoV network. Ksentini *et al.* [37] proposed a VANET to Internet protocol for QoS-enabled Internet access in vehicular networks. Their approach used a Prediction-based Routing (PBR) algorithm and the IEEE 802.11p EDCA scheme. Zhu *et al.* [38] proposed a video streaming uploading service over vehicular networks. The authors make use of the V2I and V2V communications to cooperatively forward video streams from moving vehicles to a fixed network. Another work by Razzaq and Mehaoua [39] proposed a streaming scheme over a vehicular network using network coding. In their approach, nodes along the transmission path may recover lost packets by recoding the received packets.

### B. SMART-CITIES RELATED IoV APPLICATIONS

The IoV can be used as a cost effective alternative to serve the requirements for smart cities for the large-scale data collection, transportation, and processing from smart objects within the smart city environment. Compared to traditional wireless sensor networks (WSNs), the vehicle nodes within the IoV do not suffer from the resource constraints of limited battery power and information processing limitations. Within the IoV, vehicles function as mobile smart intelligent nodes or objects within the sensing network. Each vehicle object in the smart city environment can be seen to perform four roles: (1) The vehicle object functions as nodes and peers to establish and maintain the network connectivity within the IoV itself; (2) The vehicle object functions as clients to consume services from the IoV and Internet; (3) The vehicle object functions as data collectors or "data mules" to collect and transport data from other smart objects to data centers within the smart city; (4) The vehicle object functions as a distributed computing resource to supplement the constrained information processing resources within (smaller) smart objects. Currently, surveys from many other authors have focused on the IoV for only the roles for (1) and (2). This section gives a discussion for the extended roles of (3) and (4) for IoV applications in smart cities.

The work by Bonola *et al.* [40] described an experimental evaluation for large-scale data collection from sensors in the city of Rome. In their work, 320 taxi cabs were deployed as mobile nodes to serve as oblivious data mules that move according to their day-to-day activities (i.e. the paths of the vehicle objects were not specifically designed for the data collection role). The authors showed that a network of 120 vehicles could achieve a data collection coverage of 80% of the downtown area of Rome in less than 24 hours. Another work by Khan *et al.* [41] proposed a case study of large-scale data collection from sensors through vehicular delay tolerant networks for the city of Porto. The authors approach could accommodate different types of sensors in the smart city including video sensors (cameras), noise sensors, gas sensors and meteorological sensors. In the data collection process, On-board Units (OBUs) on vehicles are used as data mules to transport the information data from sensors to the Road-side Units (RSUs). The IoV network consists of municipality vehicles, buses, taxis, and static RSUs. The authors proposed a data forwarding algorithm for data collection which depends on a proposed rank of the OBUs and the hop count of the data packet. The authors showed that their approach could increase the number of delivered packets and reduce the network overhead by limiting the number of hops travelled by a packet, as well as choosing OBUs that more frequently visit a RSU. Another work by Xu *et al.* [42] proposed a latency and coverage optimized data collection (LCODC) scheme based on vehicular ad-hoc networks for the city of Beijing. Their proposed LCODC approach used three components: (1) mobile vehicles; (2) data packets; and (3) data centers. The sensors deployed on mobile vehicles will collect data of interest when the vehicle object enters a new area. V2V transmission among vehicles are used to improve the data collection efficiency. The number of data packets that can be stored in one mobile vehicle is limited. The mobile vehicles will discard packets of less importance in the LCODC scheme. Data centers are fixed devices in the smart city and are the destinations of the transmitted data packets. The authors utilized the historical trajectories of mobile vehicles to find out patterns in the smart city and showed that their approach could reduce the latency while guaranteeing an acceptable coverage rate.

The work by Hu *et al.* [95] proposed an approach for measuring air quality in city areas by deploying a vehicular sensor network (VSN) for micro-climate monitoring. Their approach exploits the mobility of vehicles to conduct measurements at different locations. Another work by Wang and Chen [11] proposed an efficient air quality monitoring scheme for data gathering and estimation by utilizing VSNs. In their approach, a set of cars which are equipped with gas sensors, GPS receivers, and wireless interfaces (e.g., Wi-Fi, LTE-A) roam in the city and periodically report sensing data along with positions to a remote server. The authors showed that their approach (termed EDGE) gave experimental results that reduces 79–92% of sensing reports and saves 44–81% of monetary cost. The authors also identified an important social consideration in that drivers are given a monetary reward based on their reports. The authors left the issue of designing the rewarding policy for future study. Sivaraman *et al.* [96] proposed the HazeWatch project for urban air pollution monitoring in Sydney which uses low-cost mobile sensor units attached to vehicles for measuring air pollutants. Examples of other smart cities IoV applications are for structural and road monitoring, healthcare services and security. The work in [97] proposed an approach for monitoring the health of the Harvard Bridge using ubiquitous smartphones to crowdsense bridge vibration data collected from within a vehicle during daily commutes. The authors showed that there were about 18,000 and 14,000 smartphone trips over the bridge each week day and weekend respectively from which useful data for structural health monitoring could be sourced. The works in [98] and [99] proposed utilizing vehicles as mobile sensors for monitoring the conditions of roads. Yi *et al.* [98] developed a smartphone probe car (SPC) to detect and assess road surface anomalies such as potholes and bumps. Each SPC is a vehicle equipped with a mounted smartphone which reports bumping events to cloud servers. Mednis *et al.* [99] developed CarMote which is an embedded device carried on vehicles for monitoring of road surface using microphone and accelerometer sensors. The work in [94] investigated the feasibility of using boats as telemedicine infrastructure MULEs to collect medical ultrasound data from the isolated Amazon region for transportation to the main city in Brazil. Lee *et al.* [100] proposed the MobEyes system which utilizes cameras on vehicular sensor networks for proactive urban monitoring and forensic data management. The authors further noted that their approach could be applied for a wide spectrum of smart cities applications (e.g. environmental pollution, road conditions and traffic congestion monitoring).

## IV. IoV ARCHITECTURES & INTERACTION MODELS

This section presents a review of some works on IoV layer architectures and interaction communication models to give background information and survey recent works before discussion of the proposed UIoV architecture in Section V.

### A. IoV LAYER ARCHITECTURES

Several authors have proposed layer architectures for the IoV [20]–[28]. Table 3 shows a summary of the proposed architectures, the year it was proposed and their characteristics. Nanjie [20] and Golestan *et al.* [21] both proposed a three-layered IoV architecture. In Nanjie's architecture, the three layers are client, connection, and cloud layers. In the connection layer, all sensors inside and outside of a vehicle are responsible to gather all environmental information such as vehicle speed and position, oil pressure, tire pressure, forward obstacle road-to-vehicle, road condition, etc., and detect specific events of interest such as driving patterns and vehicle situations. The connection layer ensures the seamless connectivity to networks and the inter-operability to support the communication models of V2V, V2R, V2P, and V2I. All information is sent to the next cloud layer. This layer offers Internet access to mobile cars for cloud-based processes. It provides the required computing resources or computational power, data storage, and processing infrastructure for

**TABLE 3. Summary of existing IoV architectures.**

| Year | Architecture | Characteristics |
|---|---|---|
| 2011 | Nanjie et al. [20] | 3 layers (client, connection and cloud) |
| 2013 | Bonomi et al. [24] | 3 layers (services, operation, infrastructure and end points) |
| 2014 | Wan et al. [22] | 3 layers (vehicle, location and cloud) |
| 2016 | Golestan et al. [21] | 3 layers (client, connection and cloud) |
| 2017 | Gandotra et al. [23] | 3 layers (D2D area network, network management and D2D application) |
| 2016 | Kaiwartya et al. [25] | 5 layers (perceptron, coordination, AI, application and business) |
| 2017 | Fangchun et al. [26] | 4 layers (environment sense and control, network access and transport, coordination computing control and application) |
| 2017 | Juan et al. [27], [28] | 7 layers (user interface, data acquisition, data filtering and pre-processing, communication, control, management and security) |

IoV needs and contains statistical tools. It is responsible for storage, processing, analysis and decision making.

Golestan *et al.* [21] proposed the architecture for Internet of Car. The authors' works focused on situation awareness (SA) in connected cars and the road safety frameworks in cooperating SA. Wan *et al.* [22] also proposed a three-layered architecture but it is slightly different from the above two architectures. Their work focused on the context aware vehicular cyber physical systems with cloud support. Their architecture consists of vehicular, location computation, and cloud layers. The first layer focuses on data acquisition from the internal sensors in the vehicle. The ambient and physiological data such as blood pressure, heart rate, mood behavior from car occupants are obtained using short range wireless technology. In the location computational layer, roadside equipment (RSE) deployed at strategic locations can exchange information with on board equipment (OBE) installed on vehicles passing by. Both RSE and surrounding OBE are interconnected and share context-aware traffic information and entertainment resources. This architecture allows the exchange of information with nearby cars. In the case of cars that are out of range, information exchange is achieved by using multi-hop communications with the support from roadside communication infrastructures such as RSUs. The third layer is the cloud layer which hosts services to provide access to historical traffic information. It also enables load balancing across multiple interconnected cloud systems.

The work by Gandotra *et al.* [23] also proposed a three-layered architecture for D2D communication. Their architecture is very different from the above three. It consists of D2D network, network management and D2D application layers. 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. The second layer supports IP connectivity and roaming. The third layer contains services for the application (e.g. smart homes). In 2013, Bonomi [24] from CISCO proposed a four-layered IoV architecture which consists of services, infrastructure, operation and end points layers. The end points layer covers the vehicles, software and the V2V communication through the 802.11p protocol. The infrastructure layer defines technologies which allow connections between all the participants in the IoV. The operation layer monitors the policy enforcement and the flow-based management to ensure compliance with all applicable policies to regulate the information management and flow. Finally, the fourth layer is the cloud layer. It specifies the services that the different types of cloud (e.g. public cloud, private cloud and enterprise cloud) based on a defined profile coupled with the possibility of receiving services on demand. This IoV architecture allows vehicles and drivers to be connected to the Internet and therefore enables them to have access to a broad range of service providers and facilitate commercial business services' integration with vehicles.

Kaiwartya *et al.* [25] introduced a five-layered architecture which consists of perception, coordination, artificial intelligence (AI), application, and business layers. The first layer consists of different types of sensors and actuators integrated into vehicles, RSUs, smartphone, and other personal devices. The main responsibility of this layer is to collect information from various elements of the vehicle, traffic environment and connected devices. The coordination layer is represented by a virtual universal network coordination module for heterogeneous networks including Wi-Fi, 4G/LTE, WAVE, etc. It ensures the transfer of information from the lower layer that needs to be processed in the next AI layer. The main task of this layer is to process the different structure of information received from heterogeneous networks. The information is then reassembled into a unified structure which can be identified and processed in each candidate network. The AI layer is also represented by the cloud infrastructure. This layer is responsible for storing, processing and analyzing the information from the lower layers, followed by the decision making on the selection of the best applications. The fourth layer is the application layer which represents smart applications e.g. traffic safety, web-based utility applications, etc. This layer targets to provide smart services to end users which are based on intelligent and critical analysis of processed information by the previous layer. The last layer is the business layer which applies statistical analysis to deliver strategies including graphs, flowcharts, tables and comparison to develop a business model. The authors' architecture model considers the concept of heterogeneous networks in the IoV.

Recently in 2017, Yang *et al.* [26] presented an IoV architecture with four layers. Their architecture is different from the past architectures. The first layer is vehicle network environment sensing and control layer. The environment sensing is the recognition basis for IoV services, such as services of autonomous vehicle, intelligent traffic, and vehicle information. The control of vehicle and the traffic environment object are the basis of IoV services implementation. The second layer is the network access and transport layer and its main function is to realize the network access, data processing, data analysis and data transmission. The third layer is the

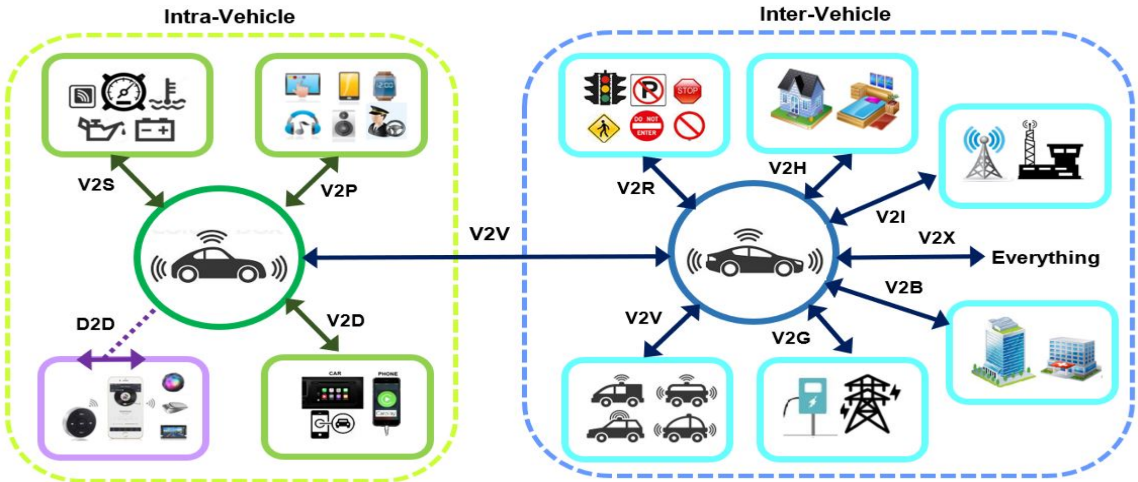


**FIGURE 2.** Interaction Models of IoV.

coordination computing control layer. This layer provides IoV applications with the network-wide capability of coordinative computing and control for human-vehicle-environment, such as data processing, resource allocation, and swarm intelligence computing. The last layer is the application layer to provide services to achieve the requirements of human-vehicle- environment coordination services.

Another group of researchers [27], [28] proposed a seven-layered IoV model architecture. Their architecture allows a transparent interconnection of all network components and data dissemination in an IoV environment. The first layer is the user interaction layer which provides a direct interaction with the driver via a management interface to coordinate all driver notifications. It also selects the best display element based on the current circumstance to assist and reduce driver distractions. The data acquisition layer aims to collect data from various sources. These include the vehicle's internal sensors, global positioning system (GPS), traffic lights, road signals, etc. The third layer is the data filtering and pre-processing layer. In this layer, the collected data is pre-processed to reduce the network traffic by eliminating irrelevant information for transmission. The criteria of transmission are based on a service profile created for the vehicle which has subscribed or active services. The communication layer aims to select the most suitable network to send the information. Selection parameters such as congestion and QoS level over the different available networks, information relevance, privacy and security among others, are taken into consideration. The fifth layer is the control and management layer. This layer globally coordinates and manages different network service providers that are within the IoV environment. Different functions and policies e.g. traffic management, traffic engineering, packet inspection are applied to manage the received information. The sixth layer which is the business layer aims to process the huge volume of information. It involves cloud computing infrastructure. This layer also consists of functions for storing, processing, and analyzing information received from lowers layers. Decision making is based on data statistical analysis. Strategies were identified to assist in applying business models based on the data usage in applications and the statistical analysis. The security layer is a transversal layer that spans across other layers to have direct communication. The security functions (e.g. data authentication, integrity, non-repudiation and confidentiality, access control, availability, etc.) can be found within the IoV architecture to support mitigating solutions for addressing various types of security attacks.

### *B. IoV INTERACTION COMMUNICATION MODELS*

Interaction communication models in the IoV ecosystem can be classified into two categories: (1) Intra-vehicle interaction models; and (2) Inter-vehicle interaction models. Fig. 2 shows a diagram of the various intra-vehicle and inter-vehicle interaction models. Several authors have presented reviews and surveys for the vehicle interaction communication models for the IoV [25]–[27]. For completeness, this section discusses some research works and challenges for the various interaction models. Table 4 shows a summary of the different IoV interaction communication models.

### *C. IoV INTRA-VEHICLE INTERACTION COMMUNICATION MODELS*

Intra-vehicle interaction models perform communications within the vehicle itself. This section gives an overview and current research for intra-vehicle communication models. In particular, we categorize and describe some research works for Vehicle-to-Sensors (V2S), Vehicle-to-Driver (V2D), and Device-to-Device (D2D) models. A summary for the intra-vehicle interaction models is shown in Table 4.

**TABLE 4. Summary of IoV interaction communication models.**

| Category | Examples of Works and Characteristics |
|---|---|
| Intra-Vehicle Interaction Communication Models | |
| Vehicle-to-Sensors (V2S) | Vehicles as sensors [83], software-defined IoV [52] |
| Vehicle-to-Driver (V2D) | Vehicle-to-Driver for motorcycle vehicle [78] |
| Device-to-Device (D2D) | D2D communication architecture [23], [27], [79], [80], [81] |
| Inter-Vehicle Interaction Communication Models | |
| Vehicle-to-Vehicle (V2V) | Vehicle tracking [43], layered architecture [27], distributive information sharing [44], VLC [45] and DSRC [46], [47] technologies |
| Vehicle-to-Pedestrian (V2P) | Wireless LAN [75], LED projection [76], protection of road users [77] |
| Vehicle-to-Roadside (V2R) | BSM broadcast [48], rapid response safety [51], SD-IoV [52], data integrity [53] & streaming [54] |
| Vehicle-to-Infrastructure (V2I) | VVLN network [45], Social IoV [56], mobile content delivery network [57], resource allocation fairness [58], ZigBee [59], other technologies [60]-[63], multi-hop connectivity [64] |
| Vehicle-to-Barrier (V2B) | V2B communication systems [51] |
| Vehicle-to-Home (V2H) | V2H backup power outage [66] |
| Vehicle-to-Everything (V2X) | Optimal information dissemination [44], LTE-based [67], MIMO [68], service flow [69] |
| Vehicle-to-Grid (V2G) | Benefits to power systems and PEVs [65],[70]-[74] |

#### 1) VEHICLE-TO-SENSORS (V2S) INTERACTION MODELS

IoV implementation requires devices such as sensors, actuators, etc. to communicate with other devices and infrastructure using different technologies. Such device interactions face several design challenges such as incompatibility among devices, internet connection issues, limited processing and storage capabilities. To address these issues, authors have proposed a comprehensive framework that supports a layered design architecture capable of providing a seamless integration for communication. Xie *et al.* [83] discussed a new era of IoV where vehicles are equipped with different kinds of sensors and become sensor nodes themselves, and propose that such vehicles will require a data acquisition system (DAS), where the vehicle data transferred on CAN networks are acquired through OBD2 (On-Broad Diagnosis) interface. The aim is to guarantee the safe operation of vehicles and improve driving experience through acquiring vehicle data in real-time in order to realize the online diagnosis. According to Chen *et al.* [52], the new IoV has brought with it the trend of equipping vehicles with versatile sensors and communication modules, bringing convenience to both drivers and passengers and with a variety of innovative ITS applications. They note that however, IoV faces many implementation challenges such as flexible and efficient connections, quality of service guarantee and multiple concurrent support requests. To this end therefore, the authors propose a service-oriented dynamic vehicular connection management in software-defined IoV (SD-IoV) that is capable of tackling the aforementioned issues by adopting the software-defined networking framework.

#### 2) VEHICLE-TO-DRIVER (V2D) INTERACTION MODELS

Spelta *et al.* [78] presented the definition and implementation of an interaction system for a vehicle-to-driver and vehicle-to-environment communication for motorcycle vehicles, based on a smartphone core and on a wireless Bluetooth medium. The motorcycle is equipped with an embedded CAN-Bluetooth converter that is interfaced with the smartphone, which acts as a gateway toward an audio helmet and a web server.

#### 3) DEVICE-TO-DEVICE (D2D) INTERACTION MODELS

Contreras-Castillo *et al.* [27] proposed a seven-layered architecture that includes a D2D interaction model that supports the functionalities, interactions, representations and information exchanges among all the devices making up the IOV ecosystem. Rose *et al.* [79] discussed D2D communications as a communication model that represents two or more devices that directly connect and communicate with one another, rather than through an intermediary application server. These devices communicate over many types of networks including IP networks or the internet. These devices use protocols like Bluetooth, Z-Wave, or ZigBee to establish direct D2D communications. Gandotra *et al.* [23] presented a detailed survey on D2D communication with its associated challenges and proposed a D2D communication architecture that ensures that users overcome the various implementation challenges, including addressing the security challenges of D2D communication. According to Ru *et al.* [80], D2D communication is an important technology for sharing spectrum with cellular users, which enables high-speed and convenient services. To tackle the current issue of spectrum resource scarcity and power allocation problem for D2D communication, the authors proposed a D2D network, where spectrum resource is shared among all D2D users and an optimization of the transmission power for each D2D transceiver to maximize system capacity. Lin *et al.* [81] noted that although increasing spectral efficiency, improving cellular coverage, reducing power consumption and improving user throughput through its pervasiveness to supporting ubiquitous healthcare applications are some of the benefits associated with a D2D assisted cellular network, it is however encumbered with some challenges and limitations; some of which include the electromagnetic interference (EMI) to medical equipment from RF transmission, the coexistence of D2D and cellular communication in the same spectrum causing cross-tier interference (CTI) to each other, etc.

### *D. IoV INTER-VEHICLE INTERACTION COMMUNICATION MODELS*

Inter-vehicle interaction models perform communications between the vehicle, other vehicles and its surrounding environments. This section gives an overview and current research for inter-vehicle communication models. In particular, we categorize and describe some research works for Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), Vehicle-to-Pedestrian (V2P), Vehicle-to-Home (V2H), Vehicle -to-Roadside (V2R), Vehicle-to-Barrier (V2B), Vehicle-to- Everything (V2X), and Vehicle-to-Grid (V2G) models. A summary for the inter-vehicle models is as shown in Table 4.

### 1) VEHICLE-TO-VEHICLE (V2V) INTERACTION MODELS

Salameh *et al.* [43] identified two different application areas of V2V communications. In the first area, the authors present a technique for better vehicle tracking using GPS information shared through the V2V communication and a vision system that supports accurate positioning. The authors discussed situations where the GPS data might be unavailable or of poor quality and a framework of several systems was established to realize a new system of Advanced Driver Assistance Systems (ADASs). In the second area, they presented a new simulated framework aimed at prototyping the whole process by combining embedded data, vision data and V2V simulations to progress towards an anti-collision application. They proposed a system architecture that uses the sensors data which are real-world GPS data and vision data to achieve the process of car tracking and the impact of V2V on collision warning. Contreras-Castillo *et al.* [27] presented a comprehensive framework that focused on interaction and network models, based on a layered architecture aimed at providing a seamless integration for V2V communication in the IoV system. Chiti *et al.* [44] proposed two matching-based user association methods, which investigate the optimization of information dissemination in IoV aimed at maximizing the information sharing among vehicles, and satisfying LTE communication QoS requirements and capacity limitations in a distributive manner. They also proposed a peer-to-peer network scheme where each vehicle will establish multiple and independent connections with other nodes in order to achieve the optimal network connectivity. Bazzi *et al.* [45] focus on the adoption of an emergent technology known as Visible Light Communication (VLC) as a supplementary technology to Designated Short-Range Communication (DSRC) and Radio Frequency (RF) for data exchange between vehicles. Their decision is predicated on the strengths of VLC such as ability to enable short range communication in large, unlicensed and uncongested bandwidths, which has advantages when compared with DSRC and LTE technologies where limited bandwidth is shared among several applications.

Lou *et al.* [46] proposed an innovative framework for a distributed traffic monitoring and information aggregation based on V2V DSRC communications. Their proposed algorithm is meant to monitor and report vehicular traffic information for both congested and uncongested cases, unlike many distributed algorithms in VANETs which are mostly limited to congestion detection only. Gao *et al.* [47] conducted an empirical study of Dedicated Short Range Communication (DSRC) V2V performance in truck platooning scenarios. They use DSRC as a communication technology designed for vehicular environments, which by utilizing wireless radio allows vehicles to establish effective communication with nearby vehicles and road-side units. Their study exploits one of the essential benefits of DSRC which includes safety enhancement by augmenting driver's operating process, seen in a case of an intersection collision warning system which emits warning signals through DSRC when a vehicle is approaching too fast towards an intersection with red traffic light, so as to notify other vehicles and pedestrians in order to avoid collisions.

### 2) VEHICLE-TO-PEDESTRIAN (V2P) INTERACTION MODELS

Fujikami *et al.* [75] identified the issues associated with Vehicle-to-Pedestrian (V2P) communication that uses wireless local area network (WLAN) and proposed two novel methods to address the issues for collective scanning and extension receiving. Recent developments have shown that the number of cases of fatal accidents involving pedestrians at night has continued to increase despite the increased safety and convenience brought about by highly computerized vehicles. Suwa *et al.* [76] proposed a road illuminating system using the LED projection module in which the system projects image information on a road surface that enables communication between human and cars so as to reduce pedestrian's accidents at night. Merdrignac *et al.* [77] introduced a new cooperative system based on both perception and V2P communication for protection of Vulnerable Road Users (VRUs). According to the authors, protection of VRUs has become very necessary and a topic of interest for researchers. VRUs include non-motorized road users, such as pedestrians and cyclists, and persons with disabilities or reduced mobility.

### 3) VEHICLE-TO-ROADSIDE (V2R) INTERACTION MODELS

Gao *et al.* [48] utilize a novel Basic Safety Message (BSM) broadcast scheme using random linear network coding to address the message dissemination at road intersection. The BSMs will assist drivers in acquiring the local driving environment and is exceptionally crucial for vehicles at road intersections to avoid collisions. However, their proposed scheme fails to address some of the issues relating to a complete design of a robust and reliable packets routing protocol for message dissemination at road intersections. Temel *et al.* [51] envisioned that V2R communication systems can be deployed along the roads to decrease the number and severity of passenger vehicle crashes. According to the authors, providing a V2R communication between errant vehicles and roadsides can potentially lead to rapid response safety systems to detect an in-coming crash, alert the driver and take necessary precautions. The variety of ITS services and applications requires flexible and efficient connections between vehicles and roadside units (RSU) as well as among V2R and V2V. Recently, the emergence of Software Defined Networking (SDN) has triggered a reconsideration of the networking paradigm for IoV networks. SDN is seen to be not only effective at improving network flexibility and efficiency but also provides a platform for advanced network management. Chen *et al.* [52] proposed a framework called SD-IoV which is a seamless integration of SDN and IoV aimed at improving the efficiency and flexibility of resource utilization, enhance the QoS guarantee, and support multiple requests. SD-IoV has the potential to inherit the merits of SDN and is regarded as a competitive solution for implementing future IoV-based ITS. Guo *et al.* [53] proposed a data access scheme based on data integrity and importance for V2R communications. Wireless access through V2R communications can be used in public transportation vehicles for streaming applications. A hierarchical optimization framework for optimal wireless access for data streaming over V2R communications links was proposed in [54]. This framework will consider application requirements, cost of wireless connectivity for transit service provider, and the revenue of the wireless network service provider.

#### 4) VEHICLE-TO-INFRASTRUCTURE (V2I) INTERACTION MODELS

Bajaj and Khanapurkar [55] emphasized the importance of the safety of a roadway in vehicle-infrastructure communication, as safety and efficiency are major targets in V2I communications. Their work further explained the various intra-vehicular communications implemented through vehicular network controllers. Bazzi *et al.* [45] utilize Visible Light Communication (VLC) as a supplementary technology to DSRC and cellular communications for data exchange between vehicles and RSUs in vehicular networks. Based on some of the identified limitations of using VLC for pure vehicular visible light networks (VVLNs), the authors proposed that VLC be implemented with other wireless standards in future heterogeneous vehicular networks. Alam *et al.* [56] proposed cyber-physical architecture for the Social Internet of Vehicles (SIoV) which is a vehicular instance of the Social Internet of Things (SIoT). The SIoV will leverage on the existing technologies for V2I communications. Silva *et al.* [57] investigated the development of Mobile Content Delivery Vehicular Networks (MCDVN) and proposed the sigma deployment as a strategy for measuring the performance of the content delivery in infrastructure-based vehicular networks. Harigovindan *et al.* [58] investigated the use of proportional fairness (PF) as the basis of resource allocation in a multi-rate multi-lane V2I network for drive-thru internet applications. In this case, the RSU is shared by vehicles that transmit at distinct data rates and moving with different mean velocities. Taking into account the different data update rates in road information and the present evolution of V2I standards, Godoy *et al.* [59] proposed a novel auxiliary ZigBee-based architecture for the AUTOPIA communications scheme, which will enable vehicles to obtain road information from the infrastructure and adapt themselves to the current zone configuration without implementing complex routing maps. They proposed the design and implementation of a low-cost infrastructure network based on ZigBee technology to alert drivers of some unexpected circumstances on the road so they can make appropriate decisions.

Santa *et al.* [60] considered the various network technologies in the field of vehicle communications, namely, Bluetooth, ZigBee, Ultra-Wide Band (UWB), Wi-Fi, etc. and proposed the use and applicability of cellular network (CN) for both V2V and V2I communications. Dey *et al.* [61] investigated the performance of Heterogeneous wireless networks consisting of Wi-Fi, DSRC and LTE technologies to provide connectivity for V2V and V2I communications with optimal network resource allocation. In [62], while noting the importance of traffic signals for safe operations of busy intersections, the authors opine that they are nevertheless one of the major causes of travel delays in urban settings. To this end, they proposed the use of Advisory Speed Limit (ASL) control strategies based on V2I communication as an alternative to traffic signals. According to the authors, the use of ASL will smooth vehicle trajectories in stop-and-go traffic on urban streets and will perform better over CNs than over DSRC networks. Analysis of the coverage and capacity requirements of digital broadcasting, cellular communication and Dedicated Short-range Communication (DSRC) systems for the implementation of V2I communications are presented in [63], in which digital broadcasting systems are shown to be inherently capacity limited and Universal Mobile Telecommunications Systems (UMTS) are envisioned to implement the V2I link using either dedicated channel (DCH) or a multimedia broadcast/multicast service (MBMS). In typical wireless networks, multi-hop communication is a method used to establish connectivity between distant nodes. This approach is proposed in [64], where authors investigated the necessary conditions for establishing a multi-hop connectivity path between an isolated vehicle and a faraway roadside unit (RSU) through cooperative vehicles serving as intermediate relays.

#### 5) VEHICLE-TO-BARRIER (V2B) INTERACTION MODELS

Temel *et al.* [51] proposed the deployment of vehicle-to-barrier communication systems along the roads to help minimize the severity of passenger vehicle crashes often caused by run-off-road (ROR) crashes. According to the authors, more than half of the traffic fatalities witnessed on daily basis are as a result of ROR crashes, which usually involve a single vehicle. Hence, V2B communications established between vehicles and radios embedded in roadside barriers will ensure that vehicles are kept on the road as well as to mitigate ROR crashes.

#### 6) VEHICLE-TO-HOME (V2H) INTERACTION MODELS

Shin and Baldick [66] investigated Vehicle-to-Home (V2H) operation that provides backup power outage of the external electric grid. In their work, they introduce a novel optimization model that aims at maximizing backup duration, and propose a new algorithm for V2H system. Their work considered an extended system called vehicles-to-homes (Vs2Hs) capable of supplying backup power to homes without energy resources or provide more balanced backup duration to homes in the system.

#### 7) VEHICLE-TO-EVERYTHING (V2X) INTERACTION MODELS

A challenging aspect of V2X (which includes V2V and V2I) communications is the design of the user association strategy, which decides how vehicles should establish communication links with other vehicles and RSUs so as to improve the diversity of data circulating within the network. To this end, Chiti *et al.* [44] investigated the user association problem in IoV, aimed at optimizing the information dissemination within the network, and proposed an independent user association method, modelled as the Irving's Stable Fixture (ISF), where each vehicle can establish independent links with other vehicles/infrastructures without requiring its partners to be connected among themselves. Sung *et al.* [67] analyzed the motivation and operation scenarios of LTE-based V2X and introduced the use cases and service requirements. They also analyzed the major technical challenges for LTE-based V2X and proposed design aspects corresponding to those challenges. According to the authors, V2X communications technologies are grouped into four different types (Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), Vehicle-to-Network (V2N) and Vehicle-to-Pedestrian (V2P)). Motivated by both technical and industrial perspectives, the authors considered LTE-based V2X as a systematic and integrated solution for V2X communications, and remarked that with an LTE network, ubiquitous coverage can be utilized, while interoperability with commercial operators can easily be achieved. Kopacz *et al.* [68] investigated a new concept for rooftop mounted vehicular MIMO antennas for V2X communication by conducting a study on two configurations of a 2-element monopole array and a switchless reconfigurable antenna, with a focus to determining the best configurations for each antenna type based on two use cases, namely, a blind corner intersection scenario where the LOS between two vehicles is blocked by buildings and an interference avoidance scenario. Seo *et al.* [69] give an overview of the service flow and requirements of the V2X services that LTE systems are targeting, and discuss the scenarios suitable for operating LTE-based V2X services, where major challenges such as high mobility and densely populated vehicle environments are addressed to fulfil the requirements of V2X services.

#### 8) VEHICLE-TO-GRID (V2G) INTERACTION MODELS

V2G systems bring many benefits to power systems such as stabilizing energy demand and supply fluctuations and assisting Plug-in Electric Vehicle (PEV) users in reducing energy costs [70]. Fechechi *et al.* [71] present an OpenADR implementation based on a 6LowPAN wireless sensor technology (WSN) and a Constrained Application Protocol (CoAP). To show the reliability and suitability of CoAP, the authors consider the process of a user charging the Plug-in Hybrid Electric Vehicle (PHEV), which involves a self-service Kiosk that accepts credit cards and controls charging processes. In their work, the authors noted that PHEVs and PEVs are important elements of the next smart grid since they are seen as a significant transportation option to reduce greenhouse emissions. They remarked that the electricity demand of these electric vehicles can pose significant challenges to the grid. The basic idea behind the concept of V2G is to use EVs as a source of reserve power while the vehicles are parked utilize the potential of PHEVs/PEVs to transfer power to the grid. Since charging stations are connected to the kiosk using the 6LowPAN WSN technology, the authors proposed a Demand Response implementation for PEV charging stations able to use WSN technologies based on CoAP. Santoshkumar and Udaykumar [72] proposed the application of Long Term Evolution (LTE) protocol for EV to EV communication in V2G to facilitate the participation of EVs in power transaction. Their work serves as a platform for the development of 4G/5G networks for V2G communication in smart grid. Huang *et al.* [73] proposed an innovative V2G system with Networked Electric Vehicles (NEVs) including mathematical modelling and practical implementation.

Floch *et al.* [74] examine modelling and control of a large population of grid-connected plug-in electric vehicles (PEVs), and develop a partial differential equation (PDE)-based technique for aggregating large populations of grid-integrated PEVs. Yoon *et al.* [65] propose a flexible V2G smart charging coordination schemes for office buildings equipped with Electric Vehicle (EV) charging stations. The proposed V2G scheme shows potential energy cost savings by distributing the overall building electricity load with V2G coordination. Their study focuses on the coordination of the EV charging and discharging specifically for smart buildings. Another critical challenge is that V2G communication is prone to much vulnerabilities and is subject to cyber security threats, which invariably affect the effectiveness of V2G systems. Niyato *et al.* [70] take a different approach and focus on mitigating cyber risks associated with V2G systems and propose an alternative approach that involves a novel concept of using cyber insurance to transfer cyber risks from a user to a third party.

## V. NEW ARCHITECTURE OF UIoV FOR BIG DATA

This section introduces the major elements in the universal IoV (UIoV) architecture. Fig. 3 shows a diagram of the UIoV elements and the building blocks components in its layers. There are seven core layers within this architecture which are Identification Layer, Physical Objects Layer, Inter-Intra Devices Layer, Communication Layer, Cloud Services Layer, Multimedia & Big Data Computation Layer and Application Layer. Fig. 4 shows the graphical representation of the proposed infrastructure. This section also prepares readers for the detail discussion on some specific layers in Section VI. The reader can refer to the survey papers in [85] and [86] for more details on the general IoT.

### *A. IDENTIFICATION LAYER*

Within the UIoV ecosystem, identification methods serve to give each object clear identity. In general, objects in the ecosystem can be classified into two types: vehicle and non-vehicle objects. The Identification Layer has two important components (Naming and Addressing). For non-vehicle

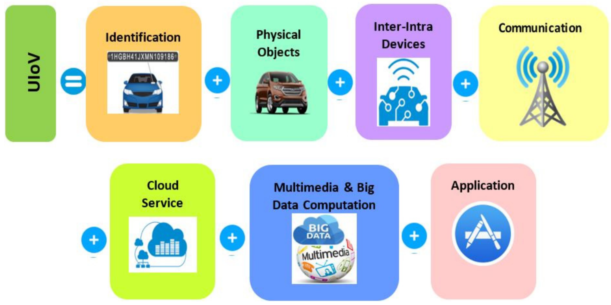


**FIGURE 3.** UIoV elements.


**FIGURE 4.** UIoV interactions for smart cities.

objects, a simple object name would be an RFID tag to represent a chip or label attached to provide the object identity. Each object is given a name or an Object ID (e.g. uCode, electronic product codes). However, two or more objects may have the same Object ID within the network and the name may not be globally unique. Thus, addressing schemes (e.g. IPv4, IPv6) can also be used to uniquely identify object identities. For vehicle objects, the Object ID could be the vehicle identification number (VIN) which is a unique code, including a serial number, used by the automotive industry to identify individual motor vehicles.

### B. PHYSICAL OBJECT LAYER

The Physical Object Layer gathers data from all objects (vehicle and non-vehicle) within the UIoV ecosystem and transmits the data to the intra-inter devices layer for further processing. Here, we focus on the UIoV where the objects are classified into non-vehicle objects and vehicle objects. The non-vehicle objects are further classified into multimedia and scalar objects. Scalar Objects have the characteristic of having a single modality (e.g. embedded sensors, wearable sensors, RFID tags) in the traditional IoT and IoV. Multimedia Objects may have a single modality (e.g. images from visual sensors) or multiple modalities (e.g. video frames which can be broken down to having an image modality and a signal (speech) modality). The characterizing of objects into vehicle objects and non-vehicle objects with different modalities is a characteristic of the UIoV which is different from the traditional IoT.

### C. INTER-INTRA DEVICES LAYER

The Inter-Intra Devices Layer is a unique layer which cannot be found in the traditional IoV architecture. This layer together with the communication layer enable the UIoV to support all types of interaction models including V2V, V2R, V2I, V2B, V2H, V2X, V2G, V2P, V2D, V2S and D2D interactions. The combination of the Inter-Intra Devices Layer and the Communication Layer within the UIoV is to connect the different and heterogeneous objects and networks to deliver specific services. There are two sub-layers called intra-device and inter-device sub-layers to support both intra-vehicle and inter-vehicle interactions.

#### 1) INTRA DEVICE SUB-LAYER

It is expected that a vehicle will be equipped with about hundreds of sensors and devices per vehicle by 2020 [88]. This sub-layer focuses on the interaction between components e.g. sensors, wearable devices, body sensor nodes, wireless motes, etc. to a central device inside the vehicle. Its functions can be data collection, information exchange between devices, etc. For data collection from the physical object layers (non-vehicle)., This sub-layer provides various forms for data collection and coordination including the in-vehicle sensor communications through Ethernet, Wi-Fi or Media Oriented System Transport (MOST) [89], vehicular personal device communications using CarPlay of Apple or Android system of OAA or Near Field Communication (NFC), etc. Research on intra-vehicle data acquisition network technologies for efficient, reliable, timely data transmissions inside the vehicle in IoV can be found in [90] and [91]. This sub layer may include some local functional units for local data processing including data filtering and pre-processing to avoid the dissemination of irrelevant information to the next communication layer and reduce the network traffic. Thus, the sub-layer can support the intra vehicle local interaction including V2P, V2D, V2S and D2D within a vehicle.

#### 2) INTER DEVICE SUB-LAYER

This sub-layer focuses on the inter vehicle interaction and data transmission between the vehicle and the external devices, sensors, vehicle, pedestrian, building and others in the IoV ecosystem. All information that is generated by other vehicles and motorcycles, pedestrians' devices, sensors, building and communication devices will be shared in real time. This information exchange will enable a variety of safety and infotainment applications via wireless communications. Due to the heterogeneous network environments in IoV, different wireless access technologies are utilized to establish connections for data collection and other purposes. The sub-layer also provides a universal network coordination for heterogeneous networks e.g. DSRC/WAVE, Wi-Fi, 4G/LTE, etc. to interact with different physical objects/ networks and provide reliable communication platforms for previous or existing technologies. Infrastructure dependent and independent wireless communication are both considered. The design and implementation would be up to the IoV architect and requirements of the target applications.

This sub-layer and its unique features enable previous research on vehicular technologies including for VANET and ITS networks to be integrated to the UIoV while ensuring standard interoperability from the communication layer onwards including the network connectivity and integration to the cloud platform at higher layers. Therefore, this sub-layer supports the all inter vehicle interaction including V2V, V2R, V2I, V2B, V2X, V2G and V2H. Meanwhile, the lack of standards, interoperability and cooperation issues among different types of networks which are the main concerns in IoV is no longer an issue in UIoV. For IoV with 'multimedia things' for multimedia applications, these things or devices have the potential to generate voluminous multimedia data and collect, process and analyze voluminous multimedia data. After data collection, data filtering and data dissemination are important to avoid the dissemination of irrelevant information and reduce the network traffic. This inter-intra devices layer has some local functional units to pre-process (e.g. data cleaning) and filter the irrelevant information. It also allows the collected data from different heterogeneous networks to be assembled into common structures which can be identified by the subsequent network(s) in the next communication layer to cloud service layer and internet.

### *D. COMMUNICATION LAYER*

The Communication Layer within the IoT is to connect the different and heterogeneous objects within the network to deliver specific services. Its aim is towards low power communications within noisy communication channels and multi-hop networks. The IEEE 802.15.4 which is a technical standard which defines the operation of low-rate wireless personal area networks (LR-WPANs) is considered. However, power consumption is not an issue in IoV. In UIoV, cellular or WiMax is considered after the Inter-Intra Devices Layer to ensure the standard and interoperability of upper layers. Cellular systems such as 4G/5G have been evolving rapidly to support the ever-increasing demands of mobile networking. WiMAX (Worldwide interoperability for Microwave Access) contains IEEE 802.16 a/e/m standards. While the IEEE 802.16 standard only supports fixed broadband wireless communications, IEEE 802.16e/mobile WiMAX standard supports speeds up to 160 km/h and different classes of quality of service, even for non-line-of-sight transmission. It is a broadband technology that offers higher capacity than WiFi network and wider coverage than cellular network. WiMAX experiences intensive standard development from fixed broadband wireless application, mobile WiMAX up to standard with 4G capabilities. This makes WiMAX a promising technology for video streaming application. WiMax also has the ability to provide reliable communication platform for abundant mobile Internet and multimedia related applications.

### *E. CLOUD SERVICES LAYER*

The UIoV cloud could be formed from the private cloud or the public cloud. Cloud virtualization technology provides a distributed or parallel computing environment to allow for scalability of IoV applications. Cloud computing provides the hardware computational platforms, infrastructure and software services to client IoV systems. The hardware infrastructure provides scalable servers and storage to give high reliability and fast computational response. An important component of software services provided by the cloud is the access centre to control the access of authorized users to ensure the security of the IoV system. The work in [87] gives a survey of 26 IoT cloud services for different application domains. The authors discuss seven challenges for the IoV cloud (standardization, heterogeneity, context-awareness, middleware, IoT node identity, energy management, and fault tolerance).

### *F. MULTIMEDIA & BIG DATA COMPUTATION LAYER*

The Multimedia and Big Data Layer consists of three sub-layers: Data Pre-processing, Big Data Computation, and Intelligent Transport sub-layers. This layer contains three components: (1) hardware; (2) software; and (3) multimedia component using divide and conquer paradigm. The hardware component includes a variety of computational components ranging from data centers, parallel GPU platforms to FPGAs and SOCs. The software component consists of library functions for Intelligent Transport System (ITS) including safety, navigation, real time traffic information, etc. Other computational components include the cloud platform which allows smart objects to send their data to the cloud for processing in real-time and then deliver results to end users from the extracted Big data. The third software component for multimedia processing and Big Data Analytics uses a divide and conquer paradigm which is discussed in the next section.

#### 1) DATA PREPROCESSING SUB-LAYER

This sub-layer serves as the pre-processing layer for data, especially the multimedia data with different modalities. It contains some important functional units including Data Pre- processing & Centralized Functional Unit and Multimedia Data Aggregation Functional Unit. The former aims to pre-process the data before sending the processed data to the next Big Data Computation sub-layer. This includes combining the data from the same object or source based on its own identity. For multimedia data with more than one modality, the data will be pre-processed and arranged according to their modalities before the identity is combined.

#### 2) BIG DATA COMPUTATION SUB-LAYER

This sub-layer is designed for Big data computation and analytics. It consists of some essential functional units for Big data computation including Divide & Conquer mechanism, data analytics, data fusion and decision making. The Divide & Conquer mechanism plays an important and fundamental role to enhance the scalability of the architecture and improve the computational efficiency of Big data processing. Others aim to provide various supports for analytics and decision making on the features extracted from the data.

#### 3) INTELLIGENT TRANSPORTATION SUB-LAYER

This sub-layer consists of library functions for Intelligent Transportation. It focuses on some specific data processing and operations which require high computational power. It has library functions for traffic sign detection and analysis, vehicle detection and vehicle tracking, incident detection, driver inattention such as distraction and fatigue detection, Pedestrian detection, lanes and object detection, automatic number plate recognition or speed cameras to monitor applications, etc. These functions can be integrated with other functions from the previous sub-layer.

### G. APPLICATION LAYER

This layer is represented by smart applications, ranging from traffic safety and efficiency to multimedia based infotainment and web based utility applications. Applications include basic management systems such as car navigation, traffic signal control systems, container management systems, automatic number plate recognition or speed cameras to monitor applications such as security CCTV systems to more advanced applications that integrate live data and feedback from a number of other sources such as parking guidance and information systems. The layer is responsible to provide smart services to end users which are based on intelligent and critical analysis of processed information by the multimedia & Big data computation layer. The Application Layer in the UIoV is responsible for providing services and determines a set of protocols for message passing.

## VI. MULTIMEDIA AND BIG DATA COMPUTATION

This section presents the Multimedia and Big Data Computation Layer with the focus on intelligent transportation in the sixth layer in UIoV. This layer consists of three sub-layers: (1) Data Pre-processing; (2) Big Data computation; and (3) Intelligent Transportation sub-layers. This layer is a core unit of Big data and multimedia data processing. It also consists of library functions to support the computation for intelligent transportation. Only essential functional units in each sub-layer are described.

### A. ESSENTIAL FUNCTIONAL UNITS IN THE DATA PRE-PROCESSING SUB-LAYER

Table 5 shows a summary and tasks for the two functional units in this sub-layer (Data Pre-processing & Centralized Functional Unit and Multimedia Data Aggregation Functional Unit. The data can be scalar or multimedia data with single or multiple modalities. Each object has its own identity and can be identified as scalar or multimedia object to know the expected type and number of modalities.

**TABLE 5. Essential functional units in data pre-processing sub-layer.**

| Function Unit | Tasks |
|---|---|
| **Data Pre-processing & Centralized Functional Unit** | • Preprocessing based on data type and modalities – some multimedia objects only produce single modality images. Some multimedia objects produce data with more than one modality e.g. video with image and speech. For scalar data or multimedia data with single modality, no data separation based on modality is performed before the combination of their unique identity. For multimedia data with more than one modality, the data will be pre-processed and arranged according to their modalities before the identity is combined.<br>• Data integration, data cleaning and data redundancy elimination, etc. to allow effective data analysis or storage. |
| **Multimedia Data Aggregation Functional Unit** | • Data aggregation and organize the data into the proper format for further processing and/or storage. Aggregation algorithms are designed to aggregate the data blocks of the same object source based on its identity and modalities:<br>(a) For scalar data or multimedia data with single modality, aggregation algorithm is performed to arrange the data into aggregated data blocks. This functional unit tries to create data blocks of equal size for further data analytics.<br>(b) For multimedia data with more than one modality, data is aggregated into partitioned data blocks for multimedia analytics. |

### B. ESSENTIAL FUNCTIONAL UNITS IN THE BIG DATA COMPUTATION SUB LAYER

This sub-layer contains the functional units for Big data computation. Some important functional units are as follows.

#### 1) DIVIDE & CONQUER COMPUTATION FUNCTIONAL UNIT

The Divide & Conquer Computation Functional Unit increases the computational efficiency and architecture scalability particularly for multimedia applications. It utilizes the divide and conquer mechanism and contains the divide and conquer sub-paths with their own computational servers to process the data of each modality efficiently for performing the parallel processing or tasks. The usage of the specific divide and conquer sub-path depends on the modality. Each sub-path aims to extract the features based on its own modality e.g. text features for text data, audio features for audio signal/speech, visual features for image data, and combination of the audio-visual features including motion features for video. The interest on the feature types for processing depends on the modalities and the application scenario. The modality of the aggregated data blocks decides which divide and conquer sub-path is selected. Each sub-path has three main functions: Divide function, Conquer function, and Customized Feature Extraction function to target the specific features. Table 6 shows a summary and some details of these

**TABLE 6.** Functions in divide & conquer.

| Function | | Tasks |
|---|---|---|
| **Divide Function** | • | Division of block recursively until the block size reaches a set threshold. It divides the incoming block into two equal parts or sub-blocks (e.g. horizontally or vertically) recursively until it reaches to the block size threshold. |
| **Customized Feature Extraction Function** | • | Extraction of target local features for each divided sub-block. The types and number of features vary for different requirements and depend on the needs of the applications: (a) Visual features – color, texture. (b) Audio features – short time Fourier transform (STFT), fast Fourier transform (FFT), mel-frequency cepstral coefficient (MFCC), zero crossing rate (ZCR), linear predictive coding (LPC). (c) Video features – motion direction and magnitude histogram, optical flows and motion patterns in specific directions. |
| **Conquer Function** | • | Combination of the sub-blocks local features. It is initiated to combine and process the features in reverse order by taking each two neighboring sub-blocks local features. The final feature block which contains the local features is the result. |

functions for Divide & Conquer. The interested reader can refer to the research works in [105] and [106] for existing divide and conquer approaches for Big data information processing.

#### 2) DATA FUSION & DECISION MAKING FUNCTIONAL UNIT

The purpose of Big data analytics is to infer and extract useful information and value from huge volumes of data. The Fusion & Decision Making Functional Unit is an essential stage of the computation layer. This unit is equipped with supporting components such as servers for the decision-making, the infrastructure for communications among computational units, and the storage devices for the extracted features and results. In this functional unit, the feature blocks of scalar or single modality are sent for decision making and the fusion process is straightforward. There is a customized design of decision mechanism for the single modality and also for a specific application. For example, the decision making for the modality can be made using machine learning techniques such as supervised learning, unsupervised learning or reinforcement learning techniques. The final process in the unit performs the integration and fusion of the features from different modalities in order to make the classification decision. Table 7 shows a summary and gives some details of these functions for Fusion & Decision Making. There are two sub-functional units: (1) Decision Level Fusion and Decision Making; and (2) Feature Level Fusion and Decision Making.

### *C. ESSENTIAL FUNCTIONAL UNITS IN THE INTELLIGENT TRANSPORTATION SUB LAYER*

Intelligent transportation systems (ITS) vary in application technologies. Smart application servers of IoV include applications for traffic safety, traffic management, service subscription and entertainment. Some of these applications require high computational power such as cognitive ITS systems or vision-based applications. This sub-layer acts as the internal processing engine. Besides its own specific library functions, it can interact with the previous sub-layers for data pre-processing, Big data processing and analysis. An ITS usually comprises of four elements: (1) Vehicles; (2) Drivers; (3) Pedestrians; and (4) Infrastructure which includes roads, traffic signs, traffic lights, and traffic control centres. The ITS sub-layer focuses on some specific data processing and computation for intelligent transportation systems such as traffic sign detection and analysis, vehicle detection and tracking, incident detection, driver inattention such as distraction and fatigue detection, pedestrian detection, lane and object detection [15], etc. Table 8 gives some details of functional units for the ITS sub-layer.

**TABLE 7.** Functions in fusion & decision making.

| Function | | Tasks |
|---|---|---|
| **Decision Level & Decision Making** | • | Target analysis provides the local decisions $D_1$ to $D_N$ based on individual modality feature blocks. The local decisions are then combined using a final decision fusion module to make a fused decision vector that is analyzed further to obtain a final decision. Advantage of scalability e.g. specific tuning in terms of the modalities used in the fusion process. |
| **Feature Level & Decision Making** | • | Target feature blocks are first combined and then used as input to the feature fusion module which merges the sets of features blocks from different modalities before the decision making. Advantage of better utilization of correlations between multiple feature blocks from different modalities at early stage. Disadvantage of difficulty in time synchronization for multimodal features. |

**TABLE 8.** Essential functional units in ITS sub-layer.

| Function Unit | | Tasks |
|---|---|---|
| **Traffic Sign Functional Unit** | • | Computation functions for traffic sign processing and analysis – shape processing, color, traffic sign priorities (e.g. danger, prohibition, warning. etc.), sign segmentation, etc. |
| **Lane & Object Detection Functional Unit** | • | Computation functions for lane/object processing and analysis – edge detection, corner-based extraction, phase congruency, etc. |
| **Pedestrian Functional Unit** | • | Computation functions for pedestrian detection and counting – facial and body localization, silhouette processing, people counting, human object tracking, etc. |
| **Vehicle Detection & Tracking Functional Unit** | • | Computation functions for vehicle detection and tracking – license plate localization, vehicle segmentation, motion processing, vehicle counting, vehicle trajectory, vehicle object tracking, etc. |

## VII. CHALLENGES FOR IoV

This section presents challenges for the IoV for deployment in smart cities from two perspectives: (1) Technological challenges; and (2) Social challenges. The section also gives some experimental insights for the dynamic nature of vehicles connected to the IoV in the smart city scenario.

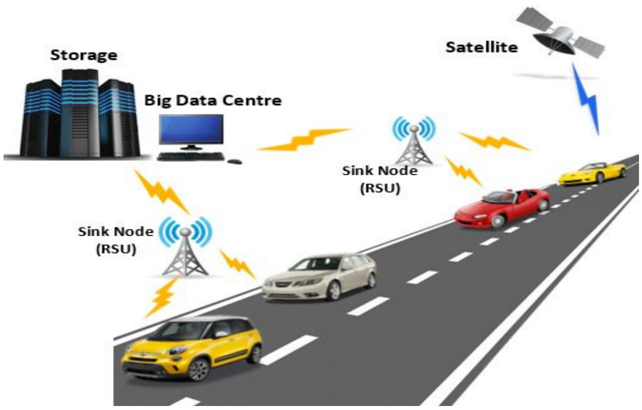


**FIGURE 5.** UIoV smart city scenario.

### A. TECHNOLOGICAL CHALLENGES

There are several technological challenges for deployment of the UIoV in smart cities. Compared to the IoT which comprises of mostly static objects, the UIoV introduces rapid mobile nodes or objects within the network structure. We perform an investigation of the effects of the dynamic nature and changing topology of the UIoV. Fig. 5 shows a basic scenario of UIoV deployment in a smart city scenario.

The IoV has a highly dynamic structure and a changing topology which may lead to link failures. This causes some effects on the packet successful delivery rate to sink nodes together with the speed of the vehicle objects. The dynamic network structure further increases the complexity of packet delivery success rate. The existing protocols in IoT do not take these into consideration, thus they cannot be directly applied in IoV with Big data collection. The recent work by Taha and Alhassan in 2018 [101] only investigated the effect of node speed on a single vehicle node in a highway scenario with medium and high mobility. We performed simulations using the RMASE simulator [102] to give experimental insights for future research direction such as the effects of a large and growing number of vehicles and the packet delivery success rate in the dynamic network structure in a smart city. The simulations were performed for two algorithms: (1) A conventional wireless routing algorithm, Adhoc On-Demand Distance Vector (AODV) [103]; and (2) A swarm intelligence routing technique termed Termite-Hill [17], [107]). The simulations used 400 mobile nodes of varying speeds to represent vehicles which were randomly distributed in a topology size of 100m×100m. The simulations were repeated ten times and the average and 95% confidence intervals are shown in Fig. 6 to Fig. 9. Fig. 6 and Fig. 7 shows the packet success rate (packet delivery) ratio with respect to different number of vehicle nodes having fixed speed of 10 m/s (36 km/h) for AODV and Termite-Hill respectively. For the conventional AODV, the packet delivery success depends significantly on the number of vehicle nodes. The Termite-Hill algorithm which is a swarm-intelligence technique is less dependent on the number of vehicle nodes.

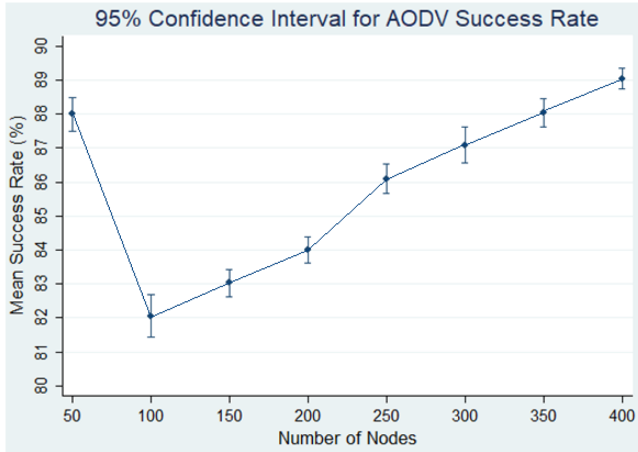


**FIGURE 6.** Packet delivery success rate for AODV with respect to different number of vehicle nodes and fixed speed of 10m/s.

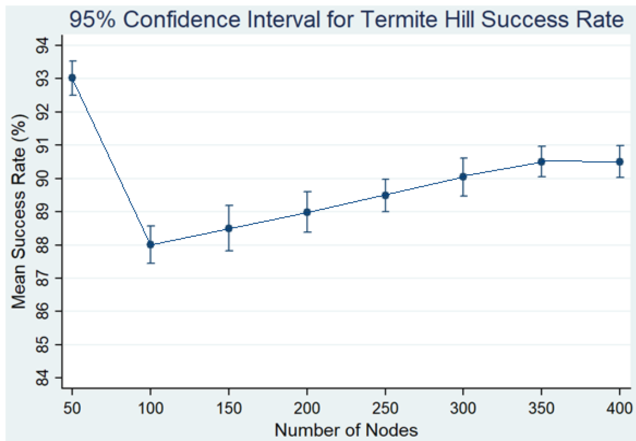


**FIGURE 7.** Packet delivery success rate for Termite-Hill with respect to different number of vehicle nodes and fixed speed of 10m/s.

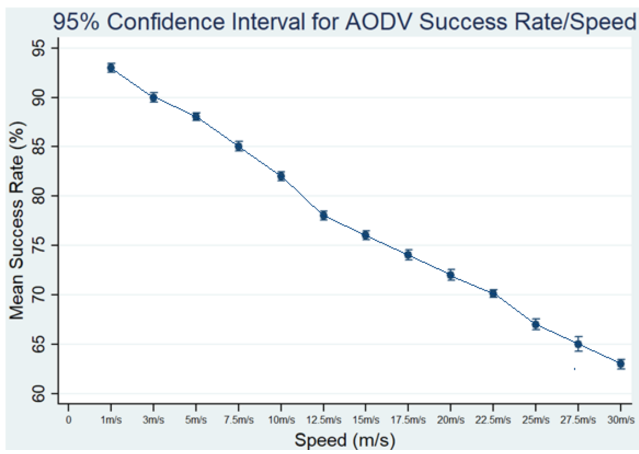


**FIGURE 8.** Packet delivery success rate for AODV with respect to different vehicle speeds.

For a further investigation, Fig. 8 and Fig. 9 shows the packet success rate with respect to increasing vehicle speeds which decreases as the vehicle speed increases for AODV and Termite-Hill respectively. These experimental results provide

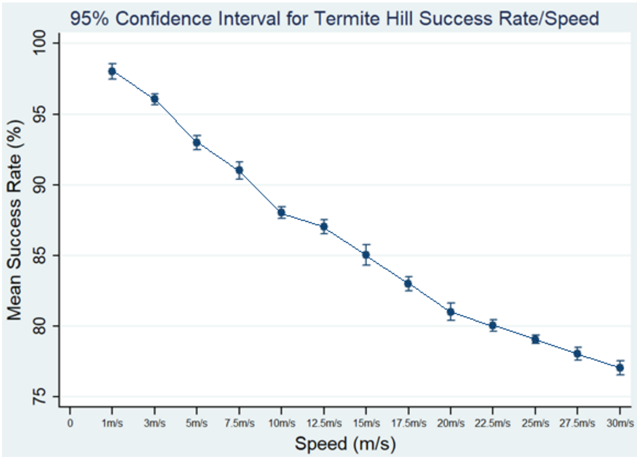


**FIGURE 9.** **Packet delivery success rate for Termite-Hill with respect to different vehicle speeds.**

some insights for future research direction for the dynamic nature of the vehicle objects and their increasing speeds in the IoV network. For the UIoV, there is a need for the development of algorithms and protocols which are less sensitive to the number of vehicle nodes, as there could be a varying number of vehicles in the network at different times and situations. Rivoirard *et al.* [104] performed simulations with real world trajectories and remarked that reactive routing protocols are more suitable to be used in sparse vehicle networks, and proactive protocols gives better performance in medium size networks. Other performance metrics (e.g. throughput, end-to-end delay, latency for real-time IoV applications) could also be investigated for future research. Other important technological challenges for the IoV is to meet the real-time constraints and be resilient to security attacks. This is particularly important for safety-based IoV applications. For example, a cooperative collision avoidance system could detect a potential incident (e.g. through a sudden brake event) and alert the neighboring vehicles. Further challenges would be to maintain high scalability and reliability throughout the heterogeneous nature of the IoV network. A final challenge would be to deal with security and privacy attacks, such as authentication and identification attacks, availability attacks, confidentiality attacks, routing attacks, and data authenticity attacks [18].

### *B. SOCIAL CHALLENGES*

Within the UIoV ecosystem for smart cities, other than technological challenges, there are also social challenges to be addressed. Wang and Chen [11] identified an important social challenge and that is the appropriate rewarding of vehicle objects to serve as data mules for data collection and transportation from smart sensors. The authors remarked that the rewarding policy may affect the operation of the UIoV network. For example, a higher reward can be given to encourage drivers to collect data from locations where pollutant concentration changes rapidly, and a lower reward given for data collected from locations where there is little variation. However, such a scheme may cause vehicles to accumulate in higher reward areas with the negative consequences of increasing traffic congestion. This remains an important area of investigation to balance the technological requirements for the optimum operation of the UIoV with suitable incentive or rewards for deployment in smart cities.

## VIII. CONCLUSION

This paper has presented a comprehensive survey of research works on existing IoV architectures, applications and vehicle interaction and communication models, followed by the proposed seven-layer UIoV architecture with multimedia and Big data computation. The UIoV represents a universal IoV architecture that enables the integration and cooperation among heterogeneous objects including multimedia devices. Besides connection to objects, some specific layers including the inter-intra devices layer also enables the connection to heterogenous networks and ensures standard interoperability for network connectivity and integration to the cloud platform at higher layers. The multimedia and Big data computation layer is also introduced to address the challenge of multimedia and Big data. This layer is also capable to identify different types of objects and arrange the data block based on its respective modalities. These data blocks are distributed among computational units and servers that follow the divide and conquer mechanism for different modalities. The advantage of computation layer is to extract the target features from Big data depending upon the user requirements. This layer has also provided some essential functions for ITS. Investigations have also been conducted investigate the effects of factors such as the dynamic topology of vehicles as moving nodes and the speed on the packet delivery success rate to sink nodes in the UIoV network structure. It is believed that substantial efforts are needed to address the open issues in order to realize the true potential of UIoV with multimedia and Big data computation in the architecture.

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