An Overview of Internet of Vehicles

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Abstract: The new era of the Internet of Things is driving the evolution of conventional Vehicle Ad-hoc Networks into the Internet of Vehicles (IoV). With the rapid development of computation and communication technologies, IoV promises huge commercial interest and research value, thereby attracting a large number of companies and researchers. This paper proposes an abstract network model of the IoV, discusses the technologies required to create the IoV, presents different applications based on certain currently existing technologies, provides several open research challenges and describes essential future research in the area of IoV.

Keywords: internet of vehicles; VANET; vehicle telematics; network model

I. INTRODUCTION

According to recent predictions[1], 25 billion "things" will be connected to the Internet by 2020, of which vehicles will constitute a significant portion. With increasing numbers of vehicles being connected to the Internet of Things (IoT), the conventional Vehicle Ad-hoc Networks (VANETs) are changing into the Internet of Vehicle (IoV). We explore the reasons for this evolution below.

As is well-known, VANET [1] turns every participating vehicle into a wireless router or mobile node, enabling vehicles to connect to each other and, in turn, create a network with a wide range. Next, as vehicles fall out of the signal range and drop out of the network, other vehicles can join in, connecting vehicles to one another to create a mobile Internet. We determine that VANET only covers a very small mobile network that is subject to mobility constraints and the number of connected vehicles. Several characteristics of large cities, such as traffic jams, tall buildings, bad driver behaviors, and complex road networks, further hinder its use. Therefore, for VANET, the objects involved are temporary, random and unstable, and the range of usage is local and discrete, i.e., VANET cannot provide whole (global) and sustainable services/applications for customers. Over the past several decades, there has not been any classic or popular implementation of VANET. The desired commercial interests have not emerged either. Therefore, VANET's usage has begun to stagnate.

In contrast to VANET, IoV has two main technology directions: vehicles' neworking and vehicles' intelligentialize. Vehicles' networking is consisting of VANET (also called vehicles' interconnection), Vehicle Telematics (also called connected vehicles) and Mobile Internet (vehicle is as a wheeled mobile terminal). Vehicles' intelligence is that the integration of driver and vehicle as a unity is more intelligent by using network technologies, which refers to the deep learning, cognitive computing, swarm computing, uncertainty artificial intelligence, etc. So, IoV focuses on the intelligent integration of humans, vehicles, things and environments and is a larger

[1] http://www.academia.edu/7037738/The_Internet_of_Things_A_Study_in_Hype_Reality_Disruption_and_Growt

network that provides services for large cities or even a whole country. IoV is an open and integrated network system with high manageability, controllability, operationalization and credibility and is composed of multiple users, multiple vehicles, multiple things and multiple networks. Based on the cooperation between computation and communication, e.g., collaborative awareness of humans and vehicles, or swarm intelligence computation and cognition, IoV can obtain, manage and compute the large scale complex and dynamic data of humans, vehicles, things, and environments to improve the computability, extensibility and sustainability of complex network systems and information services. An ideal goal for IoV is to finally realize in-depth integration of human-vehicle-thing-environment, reduce social cost, promote the efficiency of transportation, improve the service level of cities, and ensure that humans are satisfied with and enjoy their vehicles. With this definition, it is clear that VANET is only a sub network of IoV. Moreover, IoV also contains Vehicle Telematics [2], which is a term used to define a connected vehicle interchanging electronic data and providing such information services as location-based information services, remote diagnostics, on-demand navigation, and audio-visual entertainment content. For IoV, Vehicle Telematics is simply a vehicle with more complex communication technologies, and the intelligent transportation system is an application of IoV, but vehicle electronic systems do not belong to IoV.

In the last several years, the emergence of IoT, cloud computing, and Big Data has driven demand from a large number of users. Individual developers and IT enterprises have published various services/applications. However, because VANET and Vehicle Telematics lack the processing capacity for handling global (whole) information, they can only be used in short term applications or for small scale services, which limits the development and popular demand for these applications on consumer vehicles. There is a desperate need for an open and integrated network system. Therefore, the conventional Vehicle Ad-hoc Networks (VANETs), Vehicle Telematics, and other connected vehicle networks have to evolve into the Internet of Vehicle (IoV). The question accordingly arises as to why such systems did not evolve into IoT, Internet or wireless mobile networks.

The main reason is that some characteristics of IoV are different from IoT, Internet or wireless mobile networks. Firstly, in wireless mobile networks, most end-users' trajectories follow a random walk model. However, in IoV, the trajectory of vehicles is subject to the road distributions in the city. Secondly, IoT focuses on things and provides data-awareness for connected things, while the Internet focuses on humans and provides information services for humans. However, IoV focuses on the integration of humans and vehicles, in which, vehicles are an extension of a human's abilities, and humans are an extension of a vehicle's intelligence. The network model, the service model, and the behavior model of human-vehicle systems are highly different from IoT, Internet or wireless mobile network. Finally, IoV interconnects humans within and around vehicles, intelligent systems on board vehicles, and various cyber-physical systems in urban environments, by integrating vehicles, sensors, and mobile devices into a global network, thus enabling various services to be delivered to vehicles and humans on board and around vehicles. Several researchers have referred to the vehicle as a manned computer with four wheels or a manned large phone in IoV. Thus, in contrast to other networks, existing multi-user, multi-vehicle, multi-thing and multi-network systems need multi-level collaboration in IoV.

In this paper, we first provide a network model of IoV using the swarm model and an individual model. We introduce existing research work focusing on activation and maintenance of IoV. Then, we survey the various applications based on some currently existing technologies. Finally, we give several open research challenges for both the network model and the service model of human-vehicle sys-

This paper proposes an abstract network model of the IoV, discusses the technologies required to create the IoV, and presents different applications based on certain currently existing technologies, tems, i.e., enhanced communication through computation and sustainability of service providing, and outline essential future research work in the area of IoV.

The rest of this paper is organized as follows. Section 2 describes our proposed network model of IoV. The overview of IoV is presented from three different perspectives in Section 3. In Section 4, several open research challenges and essential future research work related to IoV are outlined. Finally, we present this paper's conclusions in Section 5.

II. Network Model of IOV

As shown in Fig. 1, we propose a network model of IoV based on our previous work [3], in which the model is composed of a swarm model and an individual model. The key aspect of the network model is the integration between human, vehicle, thing, and environment.

Human in IoV terminology refers to all the people who consume or provide services/applications of IoV. Human do not only contain the people in vehicles such as drivers and passengers but also the people in environment of IoV such as pedestrians, cyclists, and drivers' family members. *Vehicle* in IoV terminology refers to all vehicles that consume or provide services/applications of IoV. *Thing* in IoV terminology refers to any element other than human and vehicle. Things can be inside vehicles or outside, such as AP or road. *Environment* refers to the combination of human, vehicle and thing.

The individual model focuses on one vehicle. Through the interactions between human and environment, vehicle and environment, and thing and environment, IoV can provide services for the vehicles, the people and the things in the vehicles. In the model, the intra-vehicle network is used to support the interaction between human and vehicle, and the interaction between vehicle and thing in that vehicle. The inter-vehicle network is used

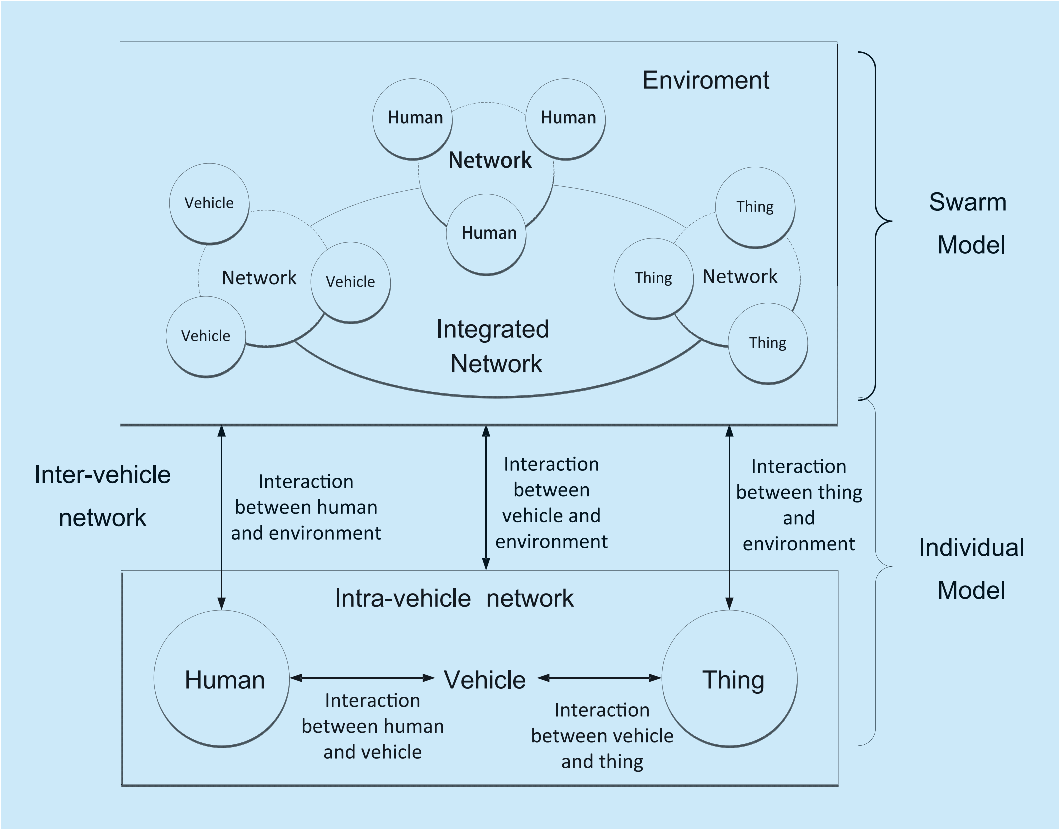

Fig.1 *Network model of IoV*

to support the interaction between human and environment, vehicle and environment, and thing and environment. Swarm model focuses on multi-user, multi-vehicle, multi-thing and multi-network scenarios. Through swarm intelligence, crowd sensing and crowd sourcing, and social computing, IoV can provide services/applications. Moreover, in this model, the interaction between human and human, vehicle and vehicle, and thing and thing, all need an integrated network to collaborate with each other and with the environment. Note that IoV has a computation platform for providing various decisions for whole network, and there are many virtual vehicles with drivers corresponding to physica vehicles and drivers. Then we call the virtual vehicle with driver as Autobot. In the IoV, Autobot can interact with each other by using swarm computing technologies and provide decision-making information for IoV in the computation platform.

III. Technology and Application of IoV

Over a decade ago, both industrial and academic researchers proposed many advanced technologies for the application layer, the mobile model & the channel model, the physical layer & the data link layer, the network layer & the transport layer, and security & privacy; these technologies are all used in IoV. In this section, we only focus on giving an overview of the technologies and their applications in IoV, and do not describe the details of the technologies. The overview describes the activation of the IoV, maintenance of the IoV, and IoV applications.

For the activation and maintenance of the IoV, we only summarize the wireless access technology and the routing technology. There are several reasons for focusing on these two technologies. Firstly, most researchers working on IoV focus on wireless access and routing, for which the number of proposed research works are the highest. Secondly, wireless access technologies play an important role in IoV. A good wireless access technology can significantly improve the quality of vehicle service, while a bad wireless access may often lead to the breakdown of services. As is well-known, routing technology is the research core of traditional networks. For IoV, while routing is still the core of the inter-vehicle network, it is also essential for delivering the control message. Finally, IoV has the two most important elements, i.e., users and network. For a simple IoV, wireless access is its user, and routing is its network. With the development of IoV, however, these elements might be less important, and other technologies may play a vital role, such as collaboration technology and swarm intelligence computing. However, due to page limitations, a detailed discussion is beyond this paper.

Note that the technologies introduced in this section cannot cover the technologies of IoV, and most of them belong to VANET [4] or Vehicle Telematics. The reason is that IoV is an open and integrated network system composed of multiple users, multiple vehicles, multiple things and multiple networks, and an integrated IoV is not described. Hence, this section mainly focuses on existing technologies and applications, even if they do not represent the technologies and applications of IoV.

3.1 Activation of IoV

There are many steps in the activation of IoV, but the most important step is to take the vehicles into the integrated network of IoV using wireless access technologies. At present, there are many existing wireless access technologies such as WLANs, WiMAX, Cellular Wireless, and satellite communications [5]. As shown in Fig. 1, most of these technologies are used to connect vehicles to each other in IoV.

WLAN contains IEEE 802.11a/b/g/n/p standards. IEEE 802.11-based WLAN, which has achieved great acceptance in the market, supports short-range, relatively high-speed data transmission. The maximum achievable data rate in the latest version (802.11n) is approximately 100 Mbps. IEEE 802.11p is a new communication standard in the IEEE 802.11 family which is based on the IEEE 802.11a.

IEEE 802.11p is designed for wireless access in the vehicular environment to support intelligent transport system applications. The use of wireless LANs in VANETs requires further research. For example, Wellens et al. [6] presented the results of an extensive measurement campaign evaluating the performance of IEEE 802.11a, b, and g in car communication scenarios, and showed that the velocity has a negligible impact, up to the maximum tested speed of 180 km/h. Yuan et al. [7] evaluated the performance of the IEEE 802.11p MAC protocol applied to V2V safety communications in a typical highway environment. WiMAX contains IEEE 802.16 a/e/m standards. IEEE 802.16 standard-based WiMAX are able to cover a large geographical area, up to 50 km, and can deliver significant bandwidth to end-users - up to 72 Mbps theoretically. While 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 transmissions. The key advantage of WiMAX compared to WLAN is that the channel access method in WiMAX uses a scheduling algorithm in which the subscriber station needs to compete only once for initial entry into the network.

Cellular wireless comprises of 3G, 4G and LTE. Current 3G networks deliver data at a rate of 384 kbps to moving vehicles, and can go up to 2 Mbps for fixed nodes. 3G systems deliver smoother handoffs compared to WLAN and WiMAX systems, and many notable works have been proposed. For example, Chao et al. [8] modeled the 3G downloading and sharing problem in integration networks. Qingwen et al. [9] made the first attempt in exploring the problem of 3G-assisted data delivery in VANETs. However, due to centralized switching at the mobile switching center (MSC) or the serving GPRS support node (SGSN), 3G latency may become an issue for many applications. Vinel [3] provided an an-

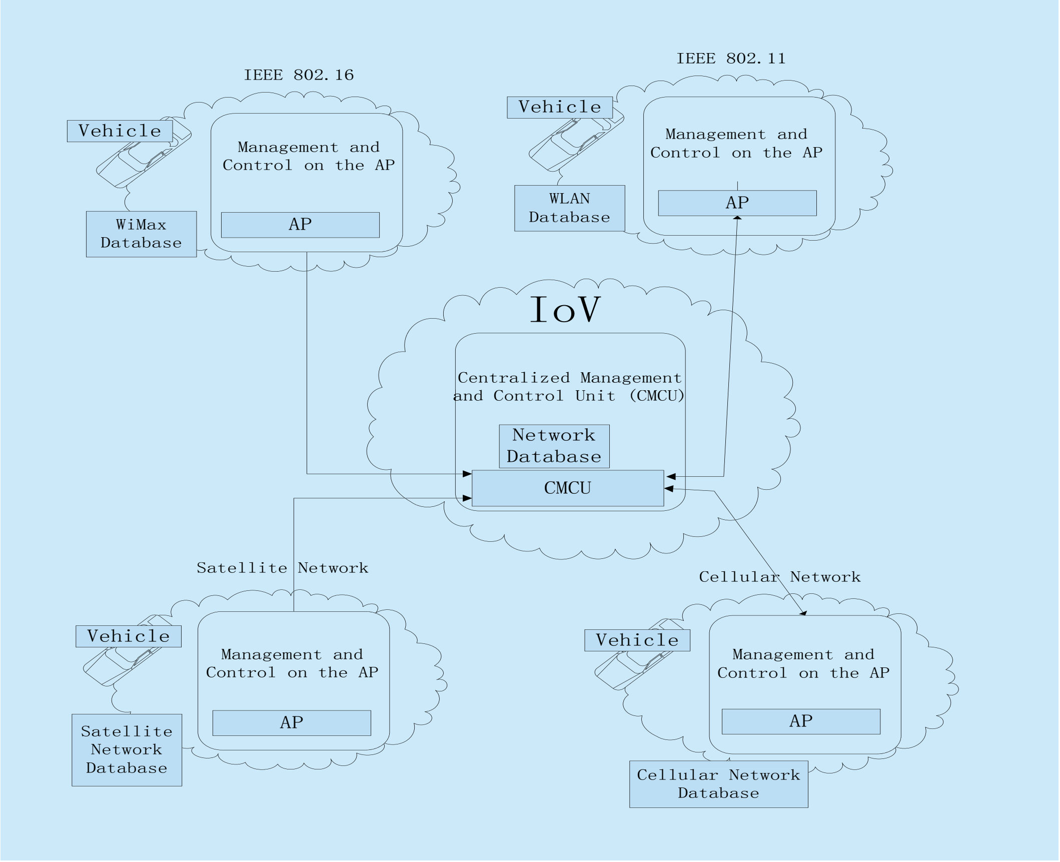

Fig.2 *Wireless access technologies in IoV*

alytical framework which allows comparing 802.11p/WAVE and LTE protocols in terms of the probability of delivering the beacon before the expiration of the deadline. Lei et al. [4] studied the potential use cases and technical design considerations in the operator controlled device-to-device communications. The potential use cases were analyzed and classified into four categories. Each use case had its own marketing challenges and the design of related techniques should take these factors into consideration. Gerla and Kleinrock [5] discussed LTE cellular service in a future urban scenario with very high bandwidth and broad range. The so-called cognitive radios will allow the user to be "best connected" all the time. For instance, in a shopping mall or in an airport lounge, LTE will become congested, and the user's cognitive radio will disconnect from LTE. For vehicles, due to large costs, satellite communications are barely used, except for GPS. It is only a supplement for temporary and emergency uses, when other communication technologies are invalid or unavailable.

Looking at the wireless access technologies described above, we think that the 4G or LTE should be the most efficient technology to launch the inter-vehicle network and to activate the IoV. The reasons are as follows. Firstly, 4G or LTE is the most used communication standard, and has been deployed by most countries to provide access services. Obviously, any vehicle can use it to connect to the IoV. Secondly, in the context of high buildings and a complex city environment, the performance of 4G or LTE is the best among all wireless access technologies. Finally, in the past ten years, the development of VANET has been very slow, and can barely be used in the real world. The main reason is that the connected vehicles cannot maintain VANET in city roads because the goals of drivers are random and different. To maintain the VANET, all vehicles must access the integrated network of IoV, after which IoV can be activated to provide services for users.

3.2 Maintenance of IoV

There are also many aspects to the maintenance of IoVs, such as data-awareness, virtual networks, and encoding, but the most important aspect is the switching of the control message for IoV. Routing technology is the suitable solution, and in IoV, is dependent on a number of factors such as velocity, density, and direction of motion of the vehicles. As shown in Fig. 1, vehicles can either be the source or the destination during the process of routing, and various standards have been built to accomplish the task of routing. With the growing needs of the users to access various resources during mobility, efficient techniques are required to support their needs and keep them satisfied.

Topology based maintenance: Because of the large overhead incurred for route discovery and route maintenance for highly mobile uncoordinated vehicles, only a few of the existing routing protocols for inter-vehicle networks are able to handle the requirements of safety applications [10,11]. An important group of routing protocols for ad-hoc networks is based on topology, and needs the establishment of an end-to-end path between the source and the destination before sending any data packet. Due to rapid changes in the network topology and highly varying communication channel conditions, the end-to-end paths determined by regular ad-hoc topology-based routing protocols are easily broken. To solve this problem, several routing protocols have been proposed [12,13] [14,15] [16] [17]. For example, Namboodiri and Gao [12] proposed a prediction-based routing for VANETs. The PBR is a reactive routing protocol, which is specifically tailored to the highway mobility scenario, to improve upon routing capabilities without using the overhead of a proactive protocol. The PBR exploits the deterministic motion pattern and speeds, to predict roughly how long an existing route between a "node" vehicle and a "gateway" vehicle will last. Using this prediction, the authors pre-emptively create new routes before the existing route lifetime expires. Toutouh et al. [13] proposed a well-known mobile ad hoc network routing protocol for VANETs to optimize parameter settings for link state routing by using an automatic optimization tool. Nzounta et al.[15] proposed a class of road-based VANET routing protocols. These protocols leverage real-time vehicular traffic information to create paths. Furthermore, geographical forwarding allows the use of any node on a road segment to transfer packets between two consecutive intersections on the path, reducing the path's sensitivity to individual node movements. Huang et al. [16] examined the efficiency of node-disjoint path routing subject to different degrees of path coupling, with and without packet redundancy. An Adaptive approach for Information Dissemination (AID) in VANETs was presented in [14], in which each node gathered the information on neighbor nodes such as distance measurements, fixed upper/lower bounds and the number of neighboring nodes. Using this information, each node dynamically adjusts the values of local parameters. The authors of this approach also proposed a rebroadcasting algorithm to obtain the threshold value. The results obtained show that AID is better than other conventional schemes in its category. Fathy et al. [17] proposed a QoS Aware protocol for improving QoS in VANET. The protocol uses Multi-Protocol Label Switching (MPLS), which runs over any Layer 2 technologies; and routers forward packets by looking at the label of the packet without searching the routing table for the next hop.

Geographic based maintaining. The geographic routing based protocols rely mainly on the position information of the destination, which is known either through the GPS system or through periodic beacon messages. By knowing their own position and the destination position, the messages can be routed directly, without knowing the topology of the network or prior route discovery. V. Naumov et al. [18] specifically designed a position-based routing protocol for inter-vehicle communication in a city and/or highway environment. Soares et al. [19] proposed the GeoSpray routing protocol, which combines store-carry-and-forward technique with routing decisions based on geographic location. These geographic locations are provided by GPS devices. In GeoSpray, authors proposed a hybrid approach, making use of a multiple copy and a single copy routing scheme. To exploit alternate paths, GeoSpray starts with multiple copy schemes which spread a limited number of bundle copies. Afterwards, it switches to a single copy scheme, which takes advantage of additional opportunities. It improves delivery success and reduces delivery delay. The protocol applies active receipts to clear the delivered bundles across the network nodes. Compared with other geographic location-based schemes, and single copy and non-location based multiple copy routing protocols, it was found that GeoSpray improves delivery probability and reduces delivery delay. In contrast to the above work, Bernsen and Manivannan proposed [20] a routing protocol for VANETs that utilizes an undirected graph representing the surrounding street layout, where the vertices of the graph are points at which streets curve or intersect, and the graph edges represent the street segments between those vertices. Unlike existing protocols, it performs real-time, active traffic monitoring and uses these data and other data gathered through passive mechanisms to assign a reliability rating to each street edge. Then, considering the different environments, a qualitative survey of position-based routing protocols was made in [21], in which the major goal was to check if there was a good candidate for both environments or not. Another perspective was offered by Liu et al. [22], who proposed a relative position based message dissemination protocol to guarantee high delivery ratio with acceptable latency and limited overhead. Campolo et al. [23] used the time, space and channel diversity to improve the efficiency and robustness of network advertisement procedures in urban scenarios.

Clustering based maintenance: In this type of routing scheme, one of the nodes among the vehicles in the cluster area becomes a clusterhead (CH), and manages the rest of the nodes, which are called cluster members. If a node falls in the communication range of two or more clusters, it is called a border node. Different protocols have been proposed for this scheme, and they differ in terms of how the CH is selected and the way the routing is done. R. S. Schwartz et al. [24] proposed a dissemination protocol suitable for both sparse and dense vehicular networks. Suppression techniques were employed in dense networks, while the store-carry-forward communication model was used in sparse networks. A. Daeinabi [25] proposed a novel clustering algorithm - vehicular clustering - based on a weighted clustering algorithm that takes into consideration the number of neighbors based on the dynamic transmission range, the direction of vehicles, the entropy, and the distrust value parameters. Wang et al. [26] refined the original PC mechanism and proposed a passive clustering aided mechanism, the main goal of which is to construct a reliable and stable cluster structure for enhancing the routing performance in VANETs. The proposed mechanism includes route discovery, route establishment, and data transmission phases. The main idea is to select suitable nodes to become clusterheads or gateways, which then forward route request packets during the route discovery phase. Each clusterhead or gateway candidate self-evaluates its qualification for clusterhead or gateway based on a priority derived from a

Table I *Relative comparison of routing protocols in IoV maintain schemes*

	Vehicle density	*Speed*	*Probabilistic Delay Routing*	*Latency*	*No. of Hops*	*Distance*	*Packet Loss*	*Throughput*	*Bandwidth*	*Feasibility*
PBR [10]	Medium	High	High	ND	Medium	Low	Medium	ND	Medium	Medium
OLSR [11]	Low	Medium	Medium	Medium	Low	ND	Low	High	Low	Low
AID [12]	High	Medium	Medium	Low	High	Medium	ND	ND	Medium	Low
eMDR [26]	High	ND	High	Medium	High	Medium	High	ND	Low	High
SADV [27]	Medium	Medium	Low	Medium	High	High	Medium	Medium	ND	Low
RBVT-R[13]	Medium	ND	Medium	Low	Medium	Medium	ND	High	Medium	Medium
QoSAware[15]	ND	ND	Low	ND	Low	Low	Medium	Low	Low	Low
CAR [16]	Medium	Medium	Low	High	ND	High	ND	Low	Low	Low
GRANT [28]	High	Medium	Low	ND	High	Low	ND	ND	ND	Low
GpsrJ+ [29]	High	Medium	Medium	High	Medium	Low	ND	ND	ND	Medium
GyTAR [30]	Medium	Medium	Low	Medium	Low	ND	ND	Medium	Medium	Medium
LOUVRE [31]	Low	ND	Low	High	High	ND	High	Low	ND	Low
GeoCross [32]	Medium	Low	Medium	Low	High	Medium	ND	ND	ND	High
GeoSpray[17]	Medium	Medium	Low	Low	ND	ND	Low	ND	High	Low
RIVER [18]	Medium	Low	ND	Medium	Medium	ND	ND	Low	Medium	Medium
GeoSVR [33]	Medium	Medium	High	Medium	High	High	Low	ND	ND	Medium
RPB-MD [20]	High	High	High	Medium	ND	ND	ND	High	Medium	High
AVRM [21]	High	Medium	Medium	High	ND	Medium	Medium	ND	High	Medium
FTLocVSDP[34]	Low	ND	Medium	Low	Low	High	Low	Medium	High	High
SRD [22]	High	High	High	ND	High	Medium	Medium	High	High	Medium
VWCA [23]	Medium	High	High	ND	Medium	ND	Low	High	High	High
PassCAR [24]	High	High	Low	Low	High	Medium	ND	Medium	Low	Low
MDDC [35]	Medium	Low	Medium	ND	Medium	Low	ND	Medium	High	Medium
C-VANETs [25]	Low	High	ND	Low	Medium	High	Medium	Medium	High	Medium
VADD [36]	ND	Low	ND	High	High	High	High	High	High	Medium
MURU [37]	High	High	Medium	Low	Medium	Medium	Low	High	High	Medium
EEDAHRP[38]	Medium	ND	Medium	Medium	Medium	Medium	ND	Low	High	Medium

ND = Not Determined

weighted combination of the proposed metrics. P. Miao [27] proposed a cooperative communication aware link scheduling scheme, with the objective of maximizing the throughput for a session in C-VANETs. They let the RSU schedule the multi-hop data transmissions among vehicles on highways by sending small sized control messages.

Based on the above overview, we provide a relative comparison of all routing protocols in Tab 1. In this table, Route length is the total distance between source and destination. PDR is the packet delivery ratio. Latency is the interval of time between the first broadcast and the end of the last host's broadcast. Latency includes buffering, queuing, transmission and propagation delays.

3.3 IoV applications

With the rapid development of numeric information technology and network technology, it is brought forward that theautomatization and intelligentization of vehicle.This gives birth to lots of applications which combine safe driving with service provision. For example, Apple CarPlay, originally introduced as iOS in vehicles, offer full-on automobile integration for Apple's Maps and turn-by-turn navigation, phone, iMeessage, and music service[5]. Similar to CarPlay, Google Android Auto provides a distraction-free interface that allows drivers enjoy the services by connecting Android devices to the vehicle. Chinese Tecent recently launched its homegrown navigation app Lubao that features user generated contents and social functions[7]. For demonstration purposes, in this paper, IoV applications can be divided into two major categories: Safety applications and User applications. Applications that increase vehicle safety and improve the safety of the passengers on the roads by notifying the vehicles about any dangerous situation in their neighborhood are called safety applications. Applications that provide value-added services are called User applications.

Technologies to enhance vehicular and passenger safety are of great interest, and one of the important applications is collision avoidance. At present, collision avoidance technologies are largely vehicle-based systems offered by original equipment manufacturers as autonomous packages which broadly serve two functions, collision warning and driver assistance. The former warns the driver when a collision seems imminent, while the latter partially controls the vehicle either for steady-state or as an emergency intervention [41]. To be specific, collision warning includes notifications about a chain car accident, warnings about road conditions such as slippery road, and approaching emergency vehicle warning [5]. On the one hand, collision warnings could be used to warn cars of an accident that occurred further along the road, thus presenting a pile-up from occurring. On the other hand, they could also be used to provide drivers with early warnings and prevent an accident from happening in the first place. Note that driving near and through intersections is one of the most complex challenges that drivers face because two or more traffic flows intersect, and the possibility of collision is high [42]. The intelligent intersection, where such conventional traffic control devices as stop signs and traffic signals are removed, has been a hot area of research for recent years. Vehicles coordinate their movement across the intersection through a combination of centralized and distributed real-time decision making, utilizing global positioning, wireless communications and in-vehicle sensing and computation[1]. A number of solutions for collision avoidance of multiple vehicles at an intersection have been proposed. A computationally efficient control law [43-45] has been derived from exploitation of the monotonicity of the vehicles' dynamics, but it has not been applied to more than two vehicles. An algorithm that addresses multi-vehicle collisions, based on abstraction, has been proposed in [46]. An algorithmic approach to enforcing safety based on a time slot assignment, which can handle a larger number of vehicles, is found in [41]. Colombo et al. [47] designed a supervisor for collision avoidance, which is based on a hybrid algorithm that employs a dynamic model of the vehicles and periodically solves a scheduling problem. The intelligent intersection is motivated by the potential benefits of comfort, safety, and efficiency. Removing the driver from negotiating the passage through complicated intersections will improve driver comfort. Furthermore, smooth coordination of vehicles through intersections will provide improvements in fuel efficiency, vehicle wear, travel time and traffic flow. It can also be switched over seamlessly at higher traffic intensities to a more traditional traffic control operation without the need for any lights, stop signs or human intervention [41].

User applications are quite varied, ranging from real-time or non-real-time multimedia streaming and interactive communications such as video-conferencing, weather information or Internet access such as data transfer, Web browsing, music download and interactive games, to roadside service applications, such as location and price lists of restaurants or gas-stations [5]. Generally speaking, user applications provide two basic user-related services: co-operative local services and global internet services. Co-operative local services are applications focusing on infotainment that can be obtained from locally based services such as point of interest notification, local electronic commerce and media downloading. Global Internet services focus on data that can be obtained from global Internet services [48]. Typical examples are community services, such as insurance and financial services, fleet management and parking zone management, which focus on software and data updates[2][3][4]. Moreover, user applications include three types of use cases. The first type gives the vehicle or the driver the freedom to access any type of information available on the Internet. The second type allows local businesses, tourist attractions, or other points of interest to advertise their availability to nearby vehicles. In this case, a roadside unit broadcasts information regarding a point of interest such as its location, hours of operation, and pricing. And the third type allows a service station to assess the state of a vehicle without making a physical connection to the vehicle. When a vehicle enters the area near a service garage, the service garage can query the vehicle for its diagnostic information to support the diagnosis of the problem reported by the customer. Even as the vehicle approaches, the vehicle's past history and the customer's information can be retrieved from a database and made available for the technician to use [49].

IV. Challenges and Future Work

The objective of IoV is to integrate multiple users, multiple vehicles, multiple things and multiple networks, to always provide the best connected communication capability that is manageable, controllable, operational, and credible. Such a network system is not currently available, but it is highly desirable for advancing the capabilities of future IoV applications. Efficient wireless access solutions will be essential for manageable and credible IoV. The solutions should consider the communication coverage limitation in a complex city. Sophisticated solutions can be developed that enhance the communication ability using diverse technologies for the IoV. The transport of big data, especially video, over the IoV, can aggravate the network burden. Efficient methods will also need to be developed for the sustainability of service providing as vehicles become mobile nodes in the global network. The integration of human and vehicle as one end-to-end user creates a new network model and service model, which are very different from existing models. These new models may disturb the operations of the IoV. New methods will be needed to assure a good quality IoV experience.

Although many challenges have been proposed, most of them have focused on the VANET or Vehicle Telematics, and few researchers have proposed the challenge of IoV from a multi-user, multi-vehicle, multi-thing and multi-network perspective. Obviously, there are many unprecedented challenges for IoV, but we only specify three challenges in this section that need to be urgently addressed:

[2] http://elib.dlr.de/48380/1/C2C-CC_manifesto_v1.1.pdf
[3] http://www.etsi.org/deliver/etsi_tr/102600_102699/102638/01.01.01_60/tr_102638v010101p.pdf
[4] http://www.safespot-eu.org/documents/D8.4.4_SAFESPOT_Applications.pdf
[5] https://www.app.com/ios/carplay
[6] http://en.wikipedia.org/wiki/Google_driverless_car
[7] http://map.qq.com/lubao

1) what is the network model and service model of human-vehicle in IoV? 2) How to enhance communication ability in IoV? 3) How to cooperate among Autobots? 4) How to assure the sustainability of service providing in IoV?

- Network model and service model of human-vehicle. We know that the network model of a user derives from the Internet and that the network model of a vehicle is from VANET, both of which have been studied for many years, with many sophisticated models published. However, realizing an efficient network model of human-vehicle is still an open problem. In the IoV, the network model of human-vehicle should be addressed to maximize the resource utilization, robustness and stability of the network. Although still an open problem, some approaches could include the use of deep learning and cognitive computing along with network link data sharing through Big Data technologies. A related issue here is focusing on finding the service and its space-time distribution characteristics by establishing a quantitative evaluation system of a typical network service requirement. The next question is whether the service model of human-vehicle would be the same as the service model of the Internet or a mobile wireless network? There is almost no research on this issue. The study of service characteristics during the process of coordination with services and network through the user participation mode of services, its evolution mechanism and trends, and the building of a cognitive learning model are all fundamental research problems. The data obtained from such research can help establish a user's service behavior, in terms of a cognitive learning model combining human, vehicle, and services, to improve the ability to cope with complex space-time change of service requirements in the IoV.
- Enhancing communication ability. Although current communication systems provide the capacity to support network performance, there is still a network bottleneck associated with wireless access parts. Joint optimization among all the layers can be challenging because solving the bottleneck requires modification of multiple communication layers. Most of the works on network optimization are derived from heuristics and simulation. A mathematical framework to characterize the interactions among the layers would be desirable. There is much work to be done to extend the communication capability to each layer. The difficulties are due to 1) dramatic changes in the channel, network element, mobility, and resource, and 2) inconsistent optimization goals in terms of users, services, and networks. To combat these problems, several modifications to the network layer have been proposed in the literature. However, these modifications could not fundamentally improve the communication ability of the IoV. Achieving a steady supply of bandwidth for IoV traffic in presence of congestion is a challenging task. We may use some intelligent technologies to enhance the communication ability, and subsequently, to reduce the redundant network traffic.
- Cooperation technologies of virtual vehicles with drivers. With the popular of in-car operating systems such as Carplay, Google Auto Link, QNX Car, more and more vehicles will be connected to IoV. Then in the computation platform of IoV, massive virtual vehicles with drivers can interact with each other, which can provide better network experience for vehicles and drivers by using cooperation technologies. The cooperation among virtual vehicles with drivers contains two phases. The first phase is information sensing and collection of physical vehicles with drivers including finding the space-time distribution characteristics and behavior characteristic of vehicles, establishing a quantitative evaluation system of service experience quality, etc. The second phase is interaction and evaluation of virtual vehicles with drivers which includes what’s the model of mixed network and

service behavior, what's its work mechanism and evolution trend, how to cope with complex space-time change of services. For example, based on the two phases, although physical two vehicles are not connectivity or not within the same scope, they also are connected and exchange information by these virtual vehicles with drivers. Or even when one vehicle is offline or stops, its virtual vehicle can continue to run with its role, and provide non-confidential data or services for other virtual vehicles.

- The sustainability of service providing. Assuring the sustainability of service providing in IoV is still a challenging task, calling for high intelligence methods, as well as a friendly network mechanism design. Vehicles in the IoV, such as "smart" vehicle, "mediocre" vehicle, "idiot" vehicle, cannot be expected to give the same type and level of services. These vehicles have coexisted for at least 30 years. There are challenges in adjusting all vehicles to provide sustainable services over heterogeneous networks in real-time, subject to limited network bandwidth, mixed wireless access, lower service platforms, and a complex city environment. Other factors of concern are mobility, network partitions and route failures, change in channel quality and data rate, and network load. Some of these have to be addressed by swarm intelligence computing at the service providing stage. To assure the sustainability of service providing in IoV, we need to understand its (e.g., an idiot vehicle's) service providing limits under extreme bandwidth demands in real-time, the provision of adequate network resources using the sparsity of high-dimensional data and the limited bandwidth of the wireless network to support the sustainability of service providing. Previous service and computation platforms are pretty much set up for a mediocre vehicle and are not fit for all vehicles in IoV.

V. CONCLUSIONS

With the rapid development of Internet and communication technologies, vehicles that often quickly move in cities or suburbs have strong computation and communication abilities. IoV is emerging as an important part of the smart or intelligent cities being proposed and developed around the world. IoV is a complex integrated network system that interconnects people within and around vehicles, intelligent systems on board vehicles, and various cyber-physical systems in urban environments. IoV goes beyond telematics, vehicle ad hoc networks, and intelligent transportation by integrating vehicles, sensors, and mobile devices into a global network to enable various services to be delivered to vehicular and transportation systems and to people on board and around vehicles. This paper first gives a network model of IoV, and later provides an abstract taxonomy of IoV activation, maintenance, and applications. Finally, an analysis of challenges and future study directions in IoV is also provided.

ACKNOWLEDGEMENTS

The work presented in this study is supported by the Natural Science Foundation of Beijing under Grant No.4132048, NSFC(61472047), and NSFC(61202435).

References

[1] A. Dua, N. Kumar, and S. Bawa, "A systematic review on routing protocols for Vehicular Ad Hoc Networks," *Vehicular Communications, 1,* vol. 1, pp. 33-52, 1// 2014.

[2] J. L. Pernin and A. Schwartz, "Economic Aspects of Multiservice Subscriber Loops in Telematics Networks," *Communications, IEEE Transactions on, 9,* vol. 30, pp. 2211-2214, 1982.

[3] L. Jing-Lin, L. Zhi-Han, and Y. Fang-Chun, "Internet of Vehicles: The Framework and Key Technologies," *JOURNAL OF BEIJING UNIVERSITY OF POSTS AND TELECOM,* vol. http://www.buptjournal.cn/CN/abstract/abstract1895.shtml, 2014.

[4] G. Hu, A. Huang, R. He, B. Ai, and Z. Chen,

"Theory analysis of the handover challenge in Express Train Access Networks (ETAN)," *Communications, China, 7,* vol. 11, pp. 92-98, 2014.

[5] E. Hossain, G. Chow, V. C. M. Leung, R. D. McLeod, J. Mišić, V. W. S. Wong, and O. Yang, "Vehicular telematics over heterogeneous wireless networks: A survey," *Computer Communications, 7,* vol. 33, pp. 775-793, 2010.

[6] M. Wellens, B. Westphal, and P. Mahonen, "Performance Evaluation of IEEE 802.11-based WLANs in Vehicular Scenarios," in *Vehicular Technology Conference, 2007. VTC2007-Spring. IEEE 65th*, 2007, pp. 1167-1171.

[7] Y. Yuan, R. Lei, L. Xue, and Z. Xingshe, "Delay analysis and study of IEEE 802.11p based DSRC safety communication in a highway environment," in *INFOCOM, 2013 Proceedings IEEE*, 2013, pp. 1591-1599.

[8] C. Chao and Z. Yanmin, "Augmenting vehicular 3G users through inter-vehicle communications," in *Wireless Communications and Networking Conference (WCNC), 2013 IEEE*, 2013, pp. 1651-1656.

[9] Z. Qingwen, Z. Yanmin, C. Chao, Z. Hongzi, and L. Bo, "When 3G Meets VANET: 3G-Assisted Data Delivery in VANETs," *Sensors Journal, IEEE, 10,* vol. 13, pp. 3575-3584, 2013.

[10] J. Chennikara-Varghese, C. Wai, O. Altintas, and C. Shengwei, "Survey of Routing Protocols for Inter-Vehicle Communications," in *Mobile and Ubiquitous Systems: Networking & Services, 2006 Third Annual International Conference on*, 2006, pp. 1-5.

[11] Y. Xia and B. Cheng, "A Vehicle Routing Problem based on intelligent batteries transfer management for the EV network," *Communications, China, 5,* vol. 11, pp. 160-170, 2014.

[12] V. Namboodiri and G. Lixin, "Prediction-Based Routing for Vehicular <emphasis emphasistype="italic">Ad Hoc</emphasis> Networks," *Vehicular Technology, IEEE Transactions on, 4,* vol. 56, pp. 2332-2345, 2007.

[13] J. Toutouh, J. Garcia-Nieto, and E. Alba, "Intelligent OLSR Routing Protocol Optimization for VANETs," *Vehicular Technology, IEEE Transactions on, 4,* vol. 61, pp. 1884-1894, 2012.

[14] M. Bakhouya, J. Gaber, and P. Lorenz, "An adaptive approach for information dissemination in Vehicular Ad hoc Networks," *Journal of Network and Computer Applications, 6,* vol. 34, pp. 1971-1978, 11// 2011.

[15] J. Nzouonta, N. Rajgure, W. Guiling, and C. Borcea, "VANET Routing on City Roads Using Real-Time Vehicular Traffic Information," *Vehicular Technology, IEEE Transactions on, 7,* vol. 58, pp. 3609-3626, 2009.

[16] H. Xiaoxia and F. Yuguang, "Performance Study of Node-Disjoint Multipath Routing in Vehicular Ad Hoc Networks," *Vehicular Technology, IEEE Transactions on, 4,* vol. 58, pp. 1942-1950, 2009.

[17] M. Fathy, S. GholamalitabarFirouzjaee, and K. Raahemifar, "Improving QoS in VANET Using MPLS," *Procedia Computer Science, 0,* vol. 10, pp. 1018-1025, // 2012.

[18] V. Naumov and T. R. Gross, "Connectivity-Aware Routing (CAR) in Vehicular Ad-hoc Networks," in *INFOCOM 2007. 26th IEEE International Conference on Computer Communications. IEEE*, 2007, pp. 1919-1927.

[19] V. N. G. J. Soares, J. J. P. C. Rodrigues, and F. Farahmand, "GeoSpray: A geographic routing protocol for vehicular delay-tolerant networks," *Inf. Fusion,* vol. 15, pp. 102-113, 2014.

[20] J. Bernsen and D. Manivannan, "RIVER: A reliable inter-vehicular routing protocol for vehicular ad hoc networks," *Computer Networks, 17,* vol. 56, pp. 3795-3807, 11/30/ 2012.

[21] A. Fonseca and T. Vazão, "Applicability of position-based routing for VANET in highways and urban environment," *Journal of Network and Computer Applications, 3,* vol. 36, pp. 961-973, 5// 2013.

[22] C. Liu and C. Chigan, "RPB-MD: Providing robust message dissemination for vehicular ad hoc networks," *Ad Hoc Networks, 3,* vol. 10, pp. 497-511, 5// 2012.

[23] C. Campolo, H. A. Cozzetti, A. Molinaro, and R. Scopigno, "Augmenting Vehicle-to-Roadside connectivity in multi-channel vehicular Ad Hoc Networks," *Journal of Network and Computer Applications, 5,* vol. 36, pp. 1275-1286, 9// 2013.

[24] R. S. Schwartz, R. R. R. Barbosa, N. Meratnia, G. Heijenk, and H. Scholten, "A directional data dissemination protocol for vehicular environments," *Computer Communications, 17,* vol. 34, pp. 2057-2071, 11// 2011.

[25] A. Daeinabi, A. G. Pour Rahbar, and A. Khademzadeh, "VWCA: An efficient clustering algorithm in vehicular ad hoc networks," *Journal of Network and Computer Applications, 1,* vol. 34, pp. 207-222, 1// 2011.

[26] S.-S. Wang and Y.-S. Lin, "PassCAR: A passive

clustering aided routing protocol for vehicular ad hoc networks," *Computer Communications, 2,* vol. 36, pp. 170-179, 1/1/ 2013.

[27] P. Miao, L. Pan, and F. Yuguang, "Cooperative Communication Aware Link Scheduling for Cognitive Vehicular Networks," *Selected Areas in Communications, IEEE Journal on, 4,* vol. 30, pp. 760-768, 2012.

[28] M. Fogue, P. Garrido, F. J. Martinez, J.-C. Cano, C. T. Calafate, and P. Manzoni, "Evaluating the impact of a novel message dissemination scheme for vehicular networks using real maps," *Transportation Research Part C: Emerging Technologies, 0,* vol. 25, pp. 61-80, 12// 2012.

[29] Y. Ding, C. Wang, and L. Xiao, "A static-node assisted adaptive routing protocol in vehicular networks," presented at the Proceedings of the fourth ACM international workshop on Vehicular ad hoc networks, Montreal, Quebec, Canada, 2007.

[30] S. Schnaufer and W. Effelsberg, "Position-based unicast routing for city scenarios," in *World of Wireless, Mobile and Multimedia Networks, 2008. WoWMoM 2008. 2008 International Symposium on a*, 2008, pp. 1-8.

[31] K. C. Lee, J. Haerri, L. Uichin, and M. Gerla, "Enhanced Perimeter Routing for Geographic Forwarding Protocols in Urban Vehicular Scenarios," in *Globecom Workshops, 2007 IEEE*, 2007, pp. 1-10.

[32] M. Jerbi, S. M. Senouci, R. Meraihi, and Y. Ghamri-Doudane, "An Improved Vehicular Ad Hoc Routing Protocol for City Environments," in *Communications, 2007. ICC '07. IEEE International Conference on*, 2007, pp. 3972-3979.

[33] K. C. Lee, M. Le, J. Harri, and M. Gerla, "LOUVRE: Landmark Overlays for Urban Vehicular Routing Environments," in *Vehicular Technology Conference, 2008. VTC 2008-Fall. IEEE 68th*, 2008, pp. 1-5.

[34] K. C. Lee, P.-C. Cheng, and M. Gerla, "GeoCross: A geographic routing protocol in the presence of loops in urban scenarios," *Ad Hoc Netw., 5,* vol. 8, pp. 474-488, 2010.

[35] L. Zheng, X. Yong, and S. Weizhen, "GeoSVR: A Geographic Stateless VANET Routing," in *Conference Anthology, IEEE*, 2013, pp. 1-7.

[36] K. Abrougui, A. Boukerche, and H. Ramadan, "Performance evaluation of an efficient fault tolerant service discovery protocol for vehicular networks," *Journal of Network and Computer Applications, 5,* vol. 35, pp. 1424-1435, 9// 2012.

[37] M. S. Kakkasageri and S. S. Manvi, "Multiagent driven dynamic clustering of vehicles in VANETs," *Journal of Network and Computer Applications, 6,* vol. 35, pp. 1771-1780, 11// 2012.

[38] Z. Jing and C. Guohong, "VADD: Vehicle-Assisted Data Delivery in Vehicular Ad Hoc Networks," in *INFOCOM 2006. 25th IEEE International Conference on Computer Communications. Proceedings*, 2006, pp. 1-12.

[39] M. Zhaomin, Z. Hao, M. Kia, and N. Pissinou, "MURU: A Multi-Hop Routing Protocol for Urban Vehicular Ad Hoc Networks," in *Mobile and Ubiquitous Systems: Networking & Services, 2006 Third Annual International Conference on*, 2006, pp. 1-8.

[40] L. Van Minh, Y. MingChuan, and G. Qing, "End-to-end Delay Assessment and Hybrid Routing Protocol for Vehicular Ad Hoc Network," *IERI Procedia, 0,* vol. 2, pp. 727-733, // 2012.

[41] H. Kowshik, D. Caveney, and P. R. Kumar, "Provable systemwide safety in intelligent intersections," *IEEE Transactions on Vehicular Technology, 3,* vol. 60, pp. 804-818, 2011.

[42] Y. Toor, P. Muhlethaler, A. Laouiti, and A. de La Fortelle, "VEHICLE AD HOC NETWORKS: APPLICATIONS AND RELATED TECHNICAL ISSUES," *Ieee Communications Surveys and Tutorials, 3,* vol. 10, pp. 74-88, 2008.

[43] V. Desaraju, H. C. Ro, M. Yang, E. Tay, S. Roth, and D. Del Vecchio, "Partial order techniques for vehicle collision avoidance: Application to an autonomous roundabout test-bed," in *Robotics and Automation, 2009. ICRA '09. IEEE International Conference on*, 2009, pp. 82-87.

[44] J. M. Duperret, M. R. Hafner, and D. Del Vecchio, "Formal design of a provably safe robotic roundabout system," in *Intelligent Robots and Systems (IROS), 2010 IEEE/RSJ International Conference on*, 2010, pp. 2006-2011.

[45] M. R. Hafner, D. Cunningham, L. Caminiti, and D. Del Vecchio, "Automated vehicle-to-vehicle collision avoidance at intersections," in *18th World Congress on Intelligent Transport Systems and ITS America Annual Meeting 2011, October 16, 2011 - October 20, 2011*, New York, NY, United states, 2011, pp. 5454-5464.

[46] A. Colombo and D. Del Vecchio, "Supervisory control of differentially flat systems based on abstraction," in *Decision and Control and European Control Conference (CDC-ECC), 2011 50th*

IEEE Conference on, 2011, pp. 6134-6139.

[47] A. Colombo and D. D. Vecchio, “Efficient algorithms for collision avoidance at intersections,” presented at the Proceedings of the 15th ACM international conference on Hybrid Systems: Computation and Control, Beijing, China, 2012.

[48] G. Karagiannis, O. Altintas, E. Ekici, G. Heijenk, B. Jarupan, K. Lin, and T. Weil, “Vehicular Networking: A Survey and Tutorial on Requirements, Architectures, Challenges, Standards and Solutions,” *Ieee Communications Surveys and Tutorials, 4,* vol. 13, pp. 584-616, 2011.

[49] H. Hartenstein and K. P. Laberteaux, “A tutorial survey on vehicular ad hoc networks,” *IEEE Communications Magazine, 6,* vol. 46, pp. 164-171, Jun 2008.

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